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FINAL REPORT

DARPA
CONCURRENT DESIGN/CONCURRENT ENGINEERING
WORKSHOP

KEY WEST, FLORIDA, DECEMBER 6-8, 1988

ORGANIZED BY
THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MA 02139

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FINAL REPORT

DARPA
CONCURRENT DESIGN/CONCURRENT ENGINEERING
WORKSHOP

KEY WEST, FLORIDA, DECEMBER 6-8, 1988

SPECIALISTS ANALYTICAL ACTIVITIES

PROCESS MODELING

PRELIMINARY DESIGN

NEW REQUIREMENTS

CD TEAM

PRODUCT PERFORMANCE

EXPERIMENTS

FABRICATION

PREVIOUS PRODUCTS OR DESIGNS

ASSEMBLY

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- FINAL PROGRAM -

DARPA CONCURRENT DESIGN (CD)/CONCURRENT ENGINEERING (CE) WORKSHOP

Tuesday, December 6

Time	
8:00-8:30	Registration*
8:30-8:50	DARPA's Interest-Parrish
8:50-9:10	DoD's Interest-Shorey
9:10-9:30	Goals of the W.S.-Nevins

A. Current Programs - Chair: Nevins

9:30-10:00	DoD TAT Study-Kelly
10:00-10:15	BREAK
10:15-12:00	DARPA Initiative in Concurrent Engineering (DICE) - Reddy, Singh, Wood
12:00-1:30	LUNCH
1:30-2:00	P&W GMAP-Lopatka
2:00-3:15	DARPA Expert Systems for Mfg. of Smart Weapons Components - Nevins, Whitney, Peters
3:15-3:30	BREAK
3:30-4:00	Army LHX Prog.-Patterson/Trotsky
4:00-4:30	AF/WAL Prog.-Shumaker
4:30-5:00	Boeing-BSD - Henry
5:00-5:30	IBM-Large Systems
5:30-6:00	STARS/SW Producibility - Moore
6:00	ADJOURN

*Registration will also be available on Monday, December 5, from 4:00p-6:00p

Wednesday, December 7

B. DoD Implementation Plans - Chair: Shorey

8:00-8:30	Industrial Insights on the DoD Concurrent Eng. Program - Istvan
8:30-9:00	The Role of Concurrent Engineering in Weapons System Acquisition - Winner
9:00-9:30	DARPA-ISTO Prog.-Isler
9:30-10:00	DoD Implementation Strategy-Shorey
10:00-10:15	BREAK

C. Technical Panel Discussions - Chair: Whitney

10:15-11:45	Panel #1 - Features as Knowledge Representation Chair: Tanenbaum
11:45-12:15	Panel #2 - User Interface Chair: Reddy
12:15-2:00	LUNCH
2:00-3:30	Panel #3 -CD Methodology/ Partitioning - Chair: Wood
3:30-3:45	BREAK
3:45-4:45	Panel #4- Theory of Geometry/Tolerance Representation Chair: Requicha
4:45-5:45	Panel #5 - Interface Standards - Chair: Bloom
6:00	ADJOURN

Thursday, December 8

8:00-9:15	Panel #6 Intelligent Database Design and Network Support Chair: Burkhart
9:15-10:15	Panel #7 CD Architecture Capability/Technology Needs Chair: Kelly
10:15-10:30	BREAK
10:30-11:30	Panel #8 Application Reaction Chair: Engen
11:30-12:30	LUNCH

D. Panel Summaries - Chair: Wool/Peters

12:30-2:30	Panel Summaries and Research Recommendations
3:00	ADJOURN

December 22, 1988

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SUMMARY

The second DARPA Workshop on Concurrent Design was held on Dec. 6-8, 1988. The purpose of the first one (Dec. 1-3, 1987) was to examine the premise that successful applications of Concurrent Design (CD)/ Concurrent Engineering (CE) have taken place in U.S. industry, and that these techniques could be employed by DoD to reduce costs, increase quality, and to reduce the procurement cycle time.

The purpose of the second one was to present a status report on DoD and DARPA activities during the past year. This included results of DoD studies on implementation options, status report on DARPA, DoD, AF/WAL, and U.S. Army programs as well as reports on CD/CE Industrial Activities of note.

Two themes emerged at last year's workshop that were reinforced this year. These are short-term and long-term approaches to CD/CE. DoD efforts in CD/CE are mainly directed at the short-term approach, while DARPA is pursuing the long-term. DoD representatives feel that CD/CE is the way to focus and implement the department's Total Quality Management objective.

The short term issue is to implement the team approach to product development as fast as possible without waiting for any new technology. Such technology is not really needed for immediate implementation of teams; instead, the main barriers are institutional: work habits and methods, procurement policies and contracting methods, management attitudes. It is likely that companies that do not adopt teams will be left behind by those that do. Note that calling it "short-term" does not mean that it can always be implemented quickly.

The long term approach is based on improving the team approach through research that gives teams better tools with which to communicate, to resolve design issues, and to predict design effects. A major purpose of the workshop was to provide feedback to DARPA on the research needs and to suggest a structure for diverse research topics.

The technical focus of the second Workshop was a series of seven panels designed to explore the various facets of the architecture for a computer-based intelligent system for CD/CE.

> The panels were:
> - Features as knowledge representation
> - User interface
> - CD methodology/partitioning
> - Theory of geometry/tolerance representation,
> - Interface standards
> - Intelligent database design and network support
> - CD architecture capability/technology needs

There was one additional panel (called Application reaction) composed of people experienced with large complex system design, from aerospace, NASA and DOE, who were asked to comment on the workshop. They commented on the research issues raised by the technical panels, the implementation strategies proposed by DoD and DARPA, the importance of the CD/CE work to DoD, and particularly the importance of starting implementation of CD/CE now.

Two concerns the organizers had before the meeting were: a) the issue of semantics, and b) whether the attendees would agree or disagree with the manner in which CD/CE architecture had been structured into 7 panels. Apparently, the workshop preparation was sufficient to make both items non-issues. Note: In preparation, each panel member

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prepared a paragraph addressing the following points: 1) research issues, 2) the status of the research and 3) recommendations for further research. These 'position papers' were then assembled and transmitted to each invitee 10 days before the actual workshop.

In general the workshop attendees' interest was very high. The consensus view was that the workshop was timely, very important because it provided a focus for this new and very important work for DoD, and that it was well supported by the groups important for this area. That is, researchers, possible implementers - aerospace and DoD suppliers, and funding agencies. The workshop went a long way to building a community for this area. Further the DOE and NASA representatives attending the meeting expressed strong interest in getting CD/CE started in their agencies.

Table 1 lists the recommendations of the various panels.

Table 1

Panel Recommendations

Panel #1 - Features as Knowledge Representation

Research Topics

Feature Semantics

> Ontology, constraint language
> Composition rules, process representation

Mapping between perspectives, levels of abstraction, modes
function $\leftrightarrow$ structure $\leftrightarrow$ process

Maintaining consistency, inconsistency

Feature catalogues, retrieval

Feature definition, extraction

Substrates:

> Distributed, persistent, databases

> Integration with other representation:
> e.g., geometry, process plans ...

Design History, Intent

Environments for feature-based design

Panel #2 - Man-Machine Interface

If people do not use our computerized design systems, then all our work is in vain. We must do design the way people do it!

We view the man-machine interface problem as one of communication.

We believe that 3-D visualization is an enabling technology for man-machine communication.

We believe that the research issues as detailed above must be actively pursued.

Panel #3 - Concurrent Engineering Methodology/Partitioning

- IDA: "Don't wait for CE research results [the CE formalism]; study existing success stories, start implementing CE now!"

- IDEF information-flow modeling

- INTROSPECT organization analysis

- CE-for-CE

- Continue these workshops (semi-annually)

Panel # 4 - *Theory of Geometry/Tolerance Representations*

Geometric information, including tolerances, is crucial for Concurrent Engineering. Theory, representations and algorithms are much better understood for nominal or ideal objects than for toleranced objects.

Continuing support for research on solid modeling is needed and a new emphasis on tolerancing is essential to tackle the many issues identified.

Remark: More information on tolerancing is available on a forthcoming report on a NSF Workshop on Mechanical Tolerancing.

Panel # 5 - *Interface Standards*

If automation technology is to be successfully applied to concurrent engineering, it is vital that the application of standards be clearly understood. Standards provide the capability of integrating "plug compatible" systems. Since concurrent engineering consists of a set of life cycle processes that must be able to communicate information continuously through the product life, uniform standards are an obvious means of insuring successful systems integration. As the prototype systems are designed and developed, it is imperative that the researchers be aware of existing and emerging standards.

Recommendations

- Product Data Framework Implementations

  - EIS (VSIC env.)

  - OLIS (PDES)

  - DES Inc. (mech. parts/PDES)

  - NIST (Level III PDES mech parts)

- Process Interface - NGC

- CD/CE Interfaces

  - DARPA DMO/DICE

  - DARPA ISTO/Mfg. testbed

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- DoD EIS
- **Feature Definition/Extraction**
- **Feature Driven Processing (e.g. First Cut)**
- **Expansion of IRDS to Support PDES**
- **CALS Testbed Network**
- **National PDES Testbed**

Panel #6 - Intelligent Database and Network Support.

- Promote commercial vendor participation in Concurrent Engineering Issues/Projects

- Learn more about relation of database and knowledge representation for concurrent engineering needs

- Review PDES model for database and knowledge representation viewpoints (3rd and 4th levels)

- Investigate neutral storage/transfer formats for generic object structures

- Research needs for version, change, and concurrency management

- Demonstrate database prototypes in real applications to assess practical needs

Panel #7 - CD Architecture Capability/Technology Needs

The panel agreed that a concurrent design environment should have the following features:

I.   The environment must support prediction or evaluation from the earliest phases of design and assist the designer to use the evaluation results for re-design. In sequential design, most evaluation is done on relatively complete, detailed designs. In fact, most analytical tools apply only to detailed designs. To design concurrently, must have the ability to evaluate partial, incomplete designs at the conceptual stage.

The evaluation must be carried out along multiple attributes reflecting the product's life-cycle: e.g., performance, life-cycle cost, manufacturability, development time, risk, supportability.

The evaluation must let the designer keep some requirements and constraints open - you won't have adequate knowledge initially to fix them.

II. The environment must support _decomposition_ of _requirements_ and _traceability_ of requirements down to design features and manufacturing processes. It must highlight trade-offs and make members of the design team aware of changes which lead to marginal increases in performance at large marginal cost.

III. The environment must support constraint and constraint propagation/tracking: who "owns" the constraints, what constraints are being violated by whom and with what consequences. This should include constraints on computational resources used to support the design effort.

IV. The environment must support collaboration and provide a means for negotiating tradeoffs.

V. The environment must support rapid calculations at low cost to permit the design team to explore a wide number of options and reduce the tendency to over design engendered by insufficient analysis.

Panel #8 - Application Reaction

The general view of the members of the Applications Reaction Panel and other industrial representatives polled is that Concurrent Engineering principles are an effective way to implement some of the objectives of Total Quality Management. CE is widely regarded as a means to shorten the development time through consideration of "downstream" elements during the concept development and detailed design activities.

The industrial representatives further expressed the unanimous view that the absence of specific CE technology or more sophisticated tools is not an inhibitor to the introduction of CE. As expressed by several observers, we must simply get on with the implementation of CE by leadership, training and organizational changes; the automation tools will follow. It was urged that joint DoD/Industry/Academe effort to create a CE roadmap be started.

Finally, the suggestion that a broad program of communication, education and training should be begun. The implementation of CE is viewed fundamentally as an organizational and leadership issue. Education of the leaders of our nation, the Congress and the Executive Branch, and the leaders of our educational system to bring to them the vision of the benefits of Total Quality Management and Concurrent Engineering as an enabling technique is essential to creating a positive environment for the real social change which is required.

ORGANIZATION

The DARPA Concurrent Design/Concurrent Engineering (CD/CE) Workshop as organized had two principal parts, namely presentations and workshop panels. The presentations were concerned with the CD/CE aims and goals of DARPA, DoD, AFWAL and U.S. Army programs. Other presentations described the status of currently funded DARPA CD/CE programs as well as industrial programs of note based on CD/CE principals.

The principal work of the Workshop was the seven technical panels designed to explore the various facets of the architectures for computer-based intelligent systems for CD/CE design. The panels were organized in a plenary serial fashion. Breakout rooms were provided for those wishing to explore further detail with the individual panels. Apparently very little use was made of these rooms.

It was intended that panel members give brief presentations of their views of the research issues, status of knowledge and implementation status of the various architecture facets. The audience would then join in the discussion. Unfortunately, the panel presenters tended to use up most of the allotted panel time leaving little or no time for comments from the floor, thus most of the comments were made in between sessions. At the end of the workshop, each panel chairman summarized the deliberations of the panel session. The technical output of the workshop consists of the panel recommendations summarized in Table 1. The recommendations were concerned with CD/CE architecture research issues, intermediate goals for testing these new systems, as well as ways of integrating this developing knowledge into current DoD programs.

Presentations

- DARPA and DoD presented the aims and goals of their respective CD/CE programs. Presentations included the DARPA Defense Manufacturing Office (DMO) - the sponsor of this Workshop; DARPA Information Science Technology Office (ISTO); the DoD Weapons Systems Support Improvement Group, the Air Force Wright-Patterson Aeronautical Laboratories Concurrent Engineering Office; and the Army LHX Program.

- The results of two recently sponsored DoD studies on implementation options:

    - "Industrial Insights on the DoD Concurrent Engineering Program"
      The Pymatuning Group, Inc.

    - "The Role of Concurrent Engineering in Weapons System Acquisition"
      The Institute for Defense Analysis

- Descriptions of DARPA-DMO programs

    - GE/UWVA DICE (DARPA Initiative in Concurrent Engineering)

    - CSDL Expert Systems for Manufacturing of Smart Weapons Components

- CD/CE Industrial Activities of note

    - Boeing Aerospace Corporation BSD "Developmental Operations (DO)" Program

    - IBM "Total Concept Facility" for the Design of Mainframe Computers

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- **P & W GMAP Program**

- **STARS/SW Producibility**

There were 96 invitees and 87 attendees, and as indicated earlier the 'community' felt that the workshop should be held bi-annually. Both the Pymatuning Group and IDA plan to mail their respective reports to each person on the invitee list.

DISCUSSION

To set the tone, DARPA articulated its role with regard to concurrent engineering. DARPA will serve as an agency which will establish priorities, set agendas and provide funding. Its focus will be on developing the technology to support the engineering process, as opposed to specific engineering products. Effective engineering process has become particularly crucial to insure the timely, cost effective delivery of advanced weapon systems. It also has a broader scope in that economic viability is also a key security issue and these process issues are central to our manufacturing capability as a nation.

There were also reviews of several ongoing programs utilizing concurrent engineering. Many of them cited institutional, rather than technological problems. Among the problems cited were accounting methods, current acquisition and bid procedures of the defense department, and uncertain metrics for the value of CD/CE. The example of CD/CE applied to IBM mainframe packaging was impressive due to the savings attributed to process improvements. In particular, unique part numbers were reduced by 50%, engineering change orders were reduced by 59% and assembly hours were reduced by 45%. Further reductions have been targeted.

While the emphasis of the conference was on the research, development and utilization of technology to improve concurrent design, there were vocal arguments (drawing mostly on the Japanese experience, as illustrated by the presentation on the DoD Technology Assessment Team [TAT] study on Japanese manufacturing) that much process improvement could be achieved with far less emphasis on computer aids, but with greater attention to management, investment decisions, education, retention of employees and basic manufacturing. The U.S. emphasis on technological solutions may reflect the conviction that we have a competitive advantage over the Japanese regarding software engineering.

The workshop included major practitioners and researchers in concurrent design and concurrent engineering. Although some participants confused concurrency with parallelism, several major themes did emerge. One phrase 'Concurrent Engineering for Concurrent Engineering' was repeated often throughout the sessions. This refers to the need to have all the communication and cooperation of the various groups required to carry out a CD/CE application already in place in order to develop CD/CE tools. The development of such tools was viewed as a significant engineering task in its own right -- one to which the methods of concurrent engineering could be successfully applied. Some of this perspective was voiced during the DICE presentations, where one of their major subprograms is 'DICE for DICE'.

An interesting cross-disciplinary example was the presentation on STARS/SW Producibility, where the methods of concurrent engineering have been applied to software development. This presentation also noted that a standard view of having many development stages each with 99% chance of success yields much less success likelihood for the entire project. In particular, an example was given where 20 modules, each at 99% success likelihood, would only yield a project success likelihood of 25%. This presentation also emphasized a need for greater contract support of risk taking, where current contractural relations emphasize risk minimization. Specifically, the

following programmatic changes were suggested: (a) investigate alternate solution paths to allow innovation and breakthroughs, (b) seek best of breed solutions, (c) assess global quality via prototypes rather than encouraging incremental development, (d) delay requirements and hardware freeze.

Features were prominent as knowledge representations for expert systems and as encapsulations of topological, functional and geometric data. There did not appear to be general agreement as to an exact definition of feature. The problems of incorporating features within existing computerized modeling paradigms (notably CAD/CAM systems) were discussed. Although no 'break-through' technologies to solve this problem were announced, there was general consensus that the geometry based modelers of today needed to evolve to modelers which will be much more capable of capturing design intent. The modeler Alpha_1 (University of Utah) was frequently mentioned as a research vehicle for exploring some of the capabilities needed for the next generation commercial CAD/CAM system. Feature recognition, via topological graphs, rather than by narrow expert systems, was cited as a methodology that has had some initial success in research environments.

There existed some tension between those using concurrent engineering as practicing design engineers and those involved in research. There were also often differences of opinion between the mechanical engineers and the computer scientists. One way this contrast occurred was that some emphasized computer architectures to encompass all of CD/CE. While deemed theoretically valuable, there was often impatience for tools that could be used now, versus waiting for the architecture. This division was often voiced in user interface discussions. One view focused on elegant automatic seamless interfaces. A contrasting view emphasized graceful retention of the human engineer in the loop, even if that meant less global automation. These exchanges, while sometimes heated, were natural and largely productive. The general theme was that there needs to be additional analysis of how the human designer works and associated development of those computer user interface tools which will facilitate that process. The research modeler 'Supersketch' was presented, with its focus on capturing conceptual design. Many appreciated its elegant interface for capturing design intent. Concern was expressed for transfer of its geometric representation of superquadrics to standard spline based CAD system.

Specific expert systems have been developed to automate narrow slices of design, but, in most cases, these 'point solutions' have not been successfully integrated into a smooth flowing process. Some notable counter examples were 'First Cut' and 'Engineous', both of which gracefully incorporate expert systems with the overall design process.

Standards, in particular PDES, were frequently mentioned as important unifying elements of the many disparate software tools. Although workshops participants appeared to universally agree with that precept, it is interesting to note that essentially none of the researchers had incorporated PDES models within their emerging systems (either prototype or development systems). The anticipated wide spread circulation of the PDES document may help to solve this problem. Note: It was pointed out the current review document is over a thousand pages.

The very model of design, whether done with hierarchical or distributed control, was disputed. The model of distributed control would call for complex computer system controls. Most of that distributed computer control is not well understood and is the subject of leading edge research. This discussion becomes relevant to effective data base design. Relational data bases have proven ineffective for multi-user access to mechanical engineering data. The transaction model for relational data bases relies upon many, frequent, short accesses, as in banking transactions. The usual engineering paradigm is for fewer, less frequent, longer transactions. As such, the performance of relational data bases is often not sufficient to support engineering enterprises. The data base ROSE is a research effort to develop a multi-user engineering data base. One of its

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major efforts is to model the multi-user engineering access to obtain satisfactory performance. Another effort undertaken at John Deere and Co. emphasized the need to have multiple views of one model. For example, one assembly may be viewed as a design assembly, as a manufacturing assembly and as a field assembly. The data base must provide access to these multiple views while providing mechanisms for change control that ensures the integrity of the data after modification by those editing under the different views.

Current commercial CAD systems do not contain sufficient tolerancing capabilities. The modeling and data representation of tolerances still has some theoretical gaps. Tolerance analysis, particularly in 3D, is just emerging and has a fragile mathematical basis.

APPENDICES

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APPENDIX A

Panel Reports

Panel #1
Features as Knowledge Representation
Marty Tenenbaum - Chair

I. Status:

A few commercial CAD systems with Ad Hoc form features

A few research prototype design-with-feature systems

A little work on feature extraction

Realization that feature issues are VERY HARD & VERY IMPORTANT

Work in progress is promising but scattered. Lacks critical mass.

II. Research Issues

Formal Definition/Semantics

Role in Knowledge Representation

Can a feasibly-sized set of features plus a user-modify and combine capability be devised that can handle realistic designs without explosion?

Do features help or hurt?

- Quality, creativity, productivity time to market, cost ...

How to capture and make use of designer intent

Features for early design, service, to engineering etc.

Feature-Driven Applications

- Process Planning
- Design Critics
- Cost Estimators
- Design for manufacturability advisor
- Redesign (e.g. for porting a design to a new mfg. process)

Standards - e.g. PDES

(related to formalizing semantics)

III. Recommendations

Research Topics

Feature Semantics

Ontology, constraint language
Composition rules, process representation

Mapping between perspectives, levels of abstraction, modes
function ↔ structure ↔ process

Maintaining consistency, inconsistency

Feature catalogues, retrieval

Feature definition, extraction

Substrates:

     Distributed, persistent, databases

     Integration with other representation:
     e.g., geometry, process plans ...

Design History, Intent

Environments for feature-based design

Panel #2
Man-Machine Interface
Ramana Reddy/John Williams - Chairs

I. Current Status

- Most general purpose UIMS tools produce Macintosh-style interfaces but have high cost, are hard to maintain and are non-portable and often inconsistent.

- 3-D geometry is not addressed in current generation of general purpose tools.

- There is no standardization in user models.

- There is little understanding of the way people represent and manipulate design information so we do not have a basis for creating the shared representation between user and machine necessary for communication.

II. Research Issues

1. The design environment should support session to session continuity (similar to the LISP environment) with a 'programming by doing' capability.

2. We must learn how to support cooperative work such as the state of the design and other's changes can be visually communicated to users.

   - change display using animation, i.e. show me what you did.

   - concept of capturing formative process of components

3. Concept of 3-D intelligent objects

   - Icons with underlying data representations

   - Object interaction tools

4. Improved UIMS toolkits supporting rapid prototyping

   - manufacturing workbench (virtual manufacturing)

   - fast analysis to guide design

5. How do we support design the way people do it? People are needed in the loop.

III.   Recommendations

If people do not use our computerized design systems, then all our work is in vain. We must do design the way people do it!

We view the man-machine interface problem as one of communication.

We believe that 3-D visualization is an enabling technology for man-machine communication.

We believe that the research issues as detailed above must be actively pursued.

A-4

Panel #3
Concurrent Engineering Methodology/Partitioning
Ralph Wood - Chair

Goal

Formalize Concurrent Engineering

- Concepts
- Principles
- Requirements
- Limitations
- Generic methods/enablers

I. Status

- Tiger-team approach successful in Japan (TAT Report - Kelly)

- Tiger-teams and CE enhancements (e.g. shared geometric model of product)/fruitfully implemented by some U.S. industries (IDA Report)

- Institututional/organizational barriers at least as great as technical issues

- Some lessons learned but no formalism yet developed (what classes of problems are amenable to what kinds of CE methods?)

- NIST leading long-term information representation effort (PDES)

- Many tackling fragments of the total problem, e.g. (from this panel):

  - configuration evaluation, parametric design, design by features

  - manufacturing directly from a solid model ("art-to-part")

  - decomposition of complexity ("partitioning")

  - advanced geometric modeling (e.g. automatic meshing, non-manifold technology)

- DARPA's newly-started Initiative in Concurrent Engineering could be an integrating vehicle.

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II. Research Issues

Understand Design/Mfg. Process and Organizational Issues to Overcome

- **Real Scenarios**
- How to evaluate conceptual design without detailed analysis
- Guidelines for when CE will/will not work

Framework for Concurrent Engineering

- Information model (e.g. PDES) and editing tools (underlying database)
- Architecture for:
  - storage/rapid retrieval of information
  - management of communications and concurrency between disciplines
  - control; planning/scheduling
  - interfaces to users and tools
- Methods and Tools:
  - advanced CAD (design by features); constraint management;
  - detailed $\rightarrow$ parameter $\rightarrow$ simulation models

Scale-Up

- Managing complexity (system performance, decomposition)
- Real (complex) problems

Testing

- Generic problem sets
- Definition of metrics

III. Recommendations

- IDA: "Don't wait for CE research results [the CE formalism]; study existing success stories, start implementing CE now!"
- IDEF information-flow modeling
- INTROSPECT organization analysis
- CE-for-CE
- Continue these workshops (semi-annually)

Panel #4
Theory of Geometry/Tolerance Representations
Ari Requicha - Chair

I. Status

A. Solid Modeling

- Fundamentals of solid modeling are reasonably well understood

- Applications supported automatically

  - Graphics
  - Mass Properties
  - Static Interference Detection
  - Kinematic Simulation
  - NC Simulation

- Commercial Modelers are Available

  - Objects of moderate complexity
  - Large resources needed

B. Tolerancing

- Theoretical foundations emerging, but not well-understood

- Experimental systems for tolerance representation under development

- Analysis and synthesis algorithms for linear chains of dimensions are available

II. Research Issues

A. Solid Modeling

- Larger geometric coverage, including complex surfaces and blends

- Better robustness and efficiency

- Scaling up (very large objects); hierarchical representations, at varying levels of detail

- Management of constraints and data dependencies; consistency issues

- Richer models: assemblies, component relationships, features, functional information

- Applications: finite element meshing, robotics, NC, inspection

- Exploiting emerging computing technologies: parallel of distributed computation

- Integrated systems

B. Tolerancing

- **Math foundations**

- **Relationship between mechanical function and required tolerances; guidelines for designers**

- **Analysis and synthesis algorithms for nonlinear, 3-D situations, for form and other geometric tolerances**

- **User interfaces that hide the math complexity of tolerancing and facilitate proper specification and interpretation**

- **Relationships between manufacturing processes, costs and tolerances**

- **Relationship between sampling inspection methods (as used in CMMs) and tolerancing specifications that constrain all points of a surface (as in ANSI standards)**

III. Recommendations

Geometric information, including tolerances, is crucial for Concurrent Engineering. Theory, representations and algorithms are much better understood for nominal or ideal objects than for toleranced objects.

Continuing support for research on solid modeling is needed and a new emphasis on tolerancing is essential to tackle the many issues identified.

Remark: More information on tolerancing is available on a forthcoming report on a NSF Workshop on Mechanical Tolerancing.

Panel #5
Interface Standards
Howard Bloom - Chair

Narrative Summary

If automation technology is to be successfully applied to concurrent engineering, it is vital that the application of standards be clearly understood. Standards provide the capability of integrating "plug compatible" systems. Since concurrent engineering consists of a set of life cycle processes that must be able to communicate information continuously through the product life, uniform standards are an obvious means of insuring successful systems integration.

As the prototype systems are designed and developed, it is imperative that the researchers be aware of existing and emerging standards. If the finished systems is to be transferred to industry, it must not be a unique system that cannot take advantage of new technologies. Therefore, existing interface standards must become a basic part of any CD/CE system. Emerging standards should be considered and incorporated as appropriate.

Status of Existing Systems

The most appropriate set of existing standards has been defined under the CALS phase 1. This is not an accident! The standards include text (SGML), graphics (PHIGS), data base query language (SQL), part drawings (IGES), network communication (ISD/OSI 7 levels), data exchange (RDA, ANSI, etc.) and data dictionary (IRDS). These standards are necessary to support the successful transfer of information between contractors, and between contractors and DOD during the weapon system development.

Standards Research

The CALS phase II is concerned with the development of a complete product data exchange specification (PDES). At this time this is a research effort involving the development of an information model that contains all the product life cycle data.

The implementation of PDES is also a research effort. The so called "Level II" involves developing a distributed knowledge base system. This involves research in feature based retrieval of data, design knowledge representation, object oriented information models, techniques for validation and verification of the PDES implementation, management of heterogeneous data systems, etc.

Assuming a framework for CD/CE can be developed, there is still significant research needed in the development of process models that can be properly interfaced to the integrated product model. In addition, a set of standard languages (e.g. for process planning) need to be implemented that make effective use of the information in the product data base.

Finally, issues such as verification and validation of the implemented process interfaces require development of application interface protocols for testing purposes.

Intermediate Results

At the present time there are projects underway to develop PDES Levels I and II for mechanical parts and rigid assemblies (PDES Inc.). The EIS project will develop a framework for studying standards needed for concurrent design. The Air Force OLIS project will study the implementation of PDES level III system. The CALS Testbed Network is demonstrating the exchange of product data using the CALS Phase I set of

standards. The NIST has several testbeds; the AMRF, the DARPA Manufacturing Testbed, and the National PDES Testbed which are being used for studying interface standards.

I. Status

- Basic standards in place

  CALS Phase I

    Text (SGML)

    Graphics (PHIGS)

    Drawings (IGES)

    Database (SQL)

    Data Exchange (RDA, ASN.1)

- Information Models

    ER (IDEFIX) | semantic model
    IA (NIAM) | (SAM*)

- Data Dictionary Framework
  IRDS (multiple views)

- Network Standards in place
  ISO/OSI 7 levels

- No accepted framework exists for CD/CE

- Classic life cycle processes well-defined

- Product data model just beginning to emerge

II. Research Issues

- Definition of product data model to support CD/CE
  (future versions of PDES)

- Platforms for support CD/CE Information requirements
  (distributed knowledge base PDES Level IV)

- Tools for Interfaces

    - Object-oriented databases and information models

    - Knowledge representation

    - Feature driven processing

- Validation and Verification of Interfaces

- Process Models

- Process Languages

- Control of information when data management is automated

- Proprietary Issues

- Query language for distributed databases for CD/CE

III. Recommendations

- Product Data Framework Implementations

  - EIS (VSIC env.)

  - OLIS (PDES)

  - DES Inc. (mech. parts/PDES)

  - NIST (Level III PDES mech parts)

- Process Interface - NGC

- CD/CE Interfaces

  - DARPA DMO/DICE

  - DARPA ISTO/Mfg. testbed

  - DoD EIS

- Feature Definition/Extraction

- Feature Driven Processing (e.g. First Cut)

- Expansion of IRDS to Support PDES

- CALS Testbed Network

- National PDES Testbed

Panel #6
Intelligent Database Design and Network Support
Roger Burkhart- Chair

I. Status

- Conventional DBMS
  SQL/Relational, Legacy Systems

- Object-Oriented PBMS
  VBASE, Gemstone, G-BASE

- Knowledge Representation Frameworks
  KEE, Knowledge Craft, ...

- CAD Database/Configuration Control Systems
  FAIM, DMCS, Sherpa, ...

- Distributed Relational DBMS
  Oracle, Ingres, SyBASE

- Distributed Heterogeneous DBMS
  INDAS, 1^2S^2, ...

II. Research Issues

- Knowledge Representation Capabilities

- Multiple Views/Perspectives

- Dynamic Schema Evolution

- Change Recording and Management

- Concurrency Control with Long Transactions

- Network Transfer and Distribution

- Programming Language Unification

- Performance

III. Recommendations

- Promote commercial vendor participation in Concurrent Engineering Issues/Projects

- Learn more about relation of database and knowledge representation for concurrent engineering needs

- Review PDES model for database and knowledge representation viewpoints (3rd and 4th levels)

- Investigate neutral storage/transfer formats for generic object structures

- Research needs for version, change, and concurrency management

- Demonstrate database prototypes in real applications to assess practical needs

Panel #7
CD Architecture Capability/Technology Needs
Clint Kelly - Chair

The panel agreed that a concurrent design environment should have the following features:

I.   The environment must support <u>prediction</u> or <u>evaluation</u> from the earliest phases of design and <u>assist the designer to use</u> the <u>evaluation results for re-design</u>. In sequential design, most evaluation is done on relatively complete, detailed designs. In fact, most analytical tools apply only to detailed designs. To design concurrently, we must have the ability to evaluate partial, incomplete designs at the conceptual stage.

The evaluation must be carried out along multiple attributes reflecting the product's life-cycle: e.g., performance, life-cycle cost, manufacturability, development time, risk, supportability.

The evaluation must let the designer keep some requirements and constraints open - you won't have adequate knowledge initially to fix them.

II.   The environment must support <u>decomposition</u> of <u>requirements</u> and <u>traceability</u> of requirements down to design features and manufacturing processes. It must highlight trade-offs and make members of the design team aware of changes which lead to marginal increases in performance at large marginal cost.

III. The environment must support constraint and constraint propagation/tracking: who "owns" the constraints, what constraints are being violated by whom and with what consequences. This should include constraints on computational resources used to support the design effort.

IV.   The environment must support collaboration and provide a means for negotiating tradeoffs.

V.   The environment must support rapid calculations at low cost to permit the design team to explore a wide number of options and reduce the tendency to over-design engendered by insufficient analysis.

Panel #8
Application Reaction
D. Travis Engen - Chair

The general view of the members of the Applications Reaction Panel and other industrial representatives polled is that Concurrent Engineering principles are an effective way to implement some of the objectives of Total Quality Management. CE is widely regarded as a means to shorten the development time through consideration of "downstream" elements during the concept development and detailed design activities.

The industrial representatives further expressed the unanimous view that the absence of specific CE technology or more sophisitcated tools is not an inhibitor to the introduction of CE. Rather management leadership and organizational issues seem to pace the implementation. The comparison with Japan was cited as an illustration of this point: Japan achieves CE through training of many workers in all facets of the business and the use of organizational techniques, not with elaborate computer-aided design or engineering systems. As expressed by several observers, we must simply get on with the implementation of CE by leadership, training and organizational changes; the automation tools will follow.

The notion of applying the principles of CE to the development of CE was praised. In this regard it was urged that joint DoD/Industry/Academe effort to create a CE roadmap be started. This would provide a forum to allow the "downstream" impacts of the full life cycle of CE to be used in the concept development and design stage of CE tool development. It would also provide a structure which the many isolated CE activities and tool development programs could use to develop a better focus.

Finally, the suggestion that a broad program of communication, education and training should be begun. The implementation of CE is viewed fundamentally as an organizational and leadership issue. Education of the leaders of our nation, the Congress and the Executive Branch, and the leaders of our educational system to bring to them the vision of the benefits of Total Quality Management and Concurrent Engineering as an enabling technique is essential to creating a positive environment for the real social change which is required.

A-15

APPENDIX B

PRESENTATIONS

DARPA-DMO

DEFENSE MANUFACTURING OFFICE
CHARTER

THE CHARTER OF DMO IS TO PROVIDE NATIONAL LEADERSHIP IN THE
DEVELOPMENT OF WORLD CLASS, HIGH PERFORMANCE DEFENSE
MANUFACTURING HAVING A SUSTAINABLE ADVANTAGE OVER COM-
PETITORS BASED UPON

* **VALUE MEASUREMENTS** SUCH AS PRODUCT DEVELOPMENT
  CYCLES, COSTS, PERFORMANCE, QUALITY AND SERVICE

* **CAPACITY FOR LEARNING AND INNOVATION** AS EVIDENCED
  BY DEVELOPMENT AND INDUSTRIAL TRANSITION OF NEW
  PROCESSING TECHNOLOGIES IN CONCERT WITH THE DEVELOP-.
  MENT OF NEW PRODUCTS

CLASSES OF DEFENSE MANUFACTURING INDUSTRY OF SPECIAL INTEREST
INCLUDE:

* THOSE MIGRATING OFFSHORE THROUGH LOSS OF COMPETITIVE
  EDGE
* THOSE WHICH MANUFACTURE ONLY FOR DOD MARKETS
* THOSE BASED UPON EMERGING TECHNOLOGIES WHICH FORM THE
  BASIS FOR NEW OR MORE EFFECTIVE WEAPONS SYSTEMS

DMO OVERVIEW

* DMO SUPPORT EFFECTIVELY SERVES AS

  - LOWER COST, LONGER TERM SOURCE OF CAPITALIZATION
  - MECHANISM FOR VALIDATION AND INSERTION OF NEW
    TECHNOLOGIES INTO PRODUCTION

* SEVERAL CANDIDATE INDUSTRIES

  - COMPOSITES   - CERAMICS

  - OPTICS   - COMPUTERS

  - SUPERCONDUCTORS   - NAVIGATION AND GUIDANCE

Linking Problem-Solving Cycles

Upstream Cycle

One-Shot Transmission of Upstream Information → **Downstream Cycle**

Upstream Cycle

Early Release of Preliminary Information

Downstream Cycle
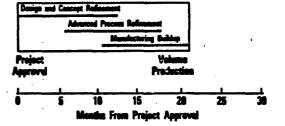
□ Problem-Solving Cycles ◁ Completeness of Upstream Output

Comparing New Product Development Approaches in Two Telecommunications Firms

Firm A: Conventional Development Paradigm: Functional Assignments

Design Engineering
Advanced Process Engineering
Manufacturing Operations

Project Approval — Volume Production

Firm B: New Development Paradigm: Task Grouping

Design and Concept Refinement
Advanced Process Refinement
Manufacturing Buildup

Project Approval — Volume Production

| 0 | 5 | 10 | 15 | 20 | 25 | 30 |

Months From Project Approval

CONTRASTING THE CONVENTIONAL AND NEW PARADIGMS
FOR PRODUCT AND PROCESS DEVELOPMENT

DARPA

DIMENSION	CONVENTIONAL PARADIGM	NEW PARADIGM
REFERENCE STAKES PROJECT COST PRODUCT/PROCESS SPECS PROJECT SCHEDULE	NONNEGOTIABLE, SET EARLY ONE SEEN AS PRIMARY DRIVER FOR THE FIRM	MAY REQUIRE OCCASIONAL REVISION ALL GIVEN SIGNIFICANT ATTENTION
PROJECT TEAM	LED BY DESIGN ENGINEERING	LED BY BROAD, EXPERIENCED BUSINESS MANAGER
PROJECT FOCUS	STARTS IN MARKETING, SHIFTS TO ENGINEERING, ENDS IN MANUFACTURING	CROSS-FUNCTIONAL TEAM EFFORT THROUGHOUT
PROJECT PHASES	SEQUENTIAL	EXTENSIVE OVERLAPPING
MANAGEMENT OBSTACLES	PEOPLE TRANSFERRED PRIORITIES CHANGED BOTTLENECKS AFFECT LIMITED DESIGN RESOURCES SLOW TURNAROUND VENDOR DELAYS EXCESSIVE ENGINEERING CHANGES	MANAGED THROUGH BETTER PLANS, DISCIPLINE, SKILLS, AND FOLLOW-THROUGH
RESPONSES TO SCHEDULE SLIPPAGES	DENY SLIPPAGE HAS OCCURRED SKIP STEPS ANNOUNCE COMPLETION, HANDOFF TO OPERATING ORGANIZATION	MUCH LESS FREQUENT, BUT ADDRESSED REALISTICALLY AS THEY ARISE
HANDLING OF KEY TASKS PROBLEM SOLVING CONFLICT RESOLUTION PROJECT ORGANIZATION	WITHIN FUNCTIONAL GROUP OR DISCIPLINE SUPPRESSED, POSTPONED, OR SENT UPSTAIRS PRIMARILY FUNCTIONAL WITH HANDOFFS	OVERLAPPING AND CROSS-FUNCTIONAL ADDRESSED EARLY AND AT LOW LEVELS HEAVYWEIGHT PROJECT MANAGERS MAINTAIN INTEGRATION
MANUFACTURING CONTROL	ONLY LOWER FORMS OF CONTROL CONSIDERED NECESSARY	PROGRESSIVE OR DYNAMIC CONTROL NECESSARY
INFORMATION TRANSFERS	LARGE BATCHES, TRANSFERRED DOWNSTREAM ONLY AFTER COMPLETION OF PHASE	MANY SMALLER TWO-WAY EXCHANGES THROUGHOUT DEVELOPMENT
EARLY MANUFACTURING INVOLVEMENT	LOOKED UPON AS (UNDESIRABLE) CONSTRAINT	BASED ON TRUST AND MUTUAL RESPECT; ADDS VALUE
DESIGN FOR MANUFACTURE		

DOD

B-3

CONCURRENT ENGINEERING PROGRAM

Concurrent Engineering
Russ Shorey, ASASD (Systems)

In my view, concurrent engineering is one of the most important areas which DoD is addressing at this time. I would also like to discuss the contributions that I feel this workshop can make to our broader objectives. First, what do I mean when I use the term "Concurrent Engineering?" Most simply, an integrated process in which the design of a product and the engineering of the processes which will manufacture and support it are done together as a single unified effort.

The intense and rapidly growing interest in this area results (of course) from perception that much shortened development schedules; improved quality; and reduced costs can accrue - all at the same time (and you will see the results of various case studies on this during the workshop). If this is such a good idea, why haven't we picked it up? First, one must say that in some cases enlightened people have moved in this direction and produced a few successes. In other cases, they have tried to move but have been only partly successful or failed. I believe the underlying problems can be addressed in terms of:

- Acquisition practices
- Management attitude
- Availability of technology

The mainstream DoD acquisition practices reflect a number of conflicting forces - many of which have tended to fractionate and segment the processes in a direction away from the integrated process represented by Concurrent Engineering. We fractionate horizontally and vertically.

We have a sequential process which attempts to achieve control by imposing checkpoints at different phases of development and in order to gain management visibility of important areas as producibility, reliability, maintainability, separate groups and separate reporting channels were established to advocate these. In some cases, these efforts have been successful, but in many other there has been a lot of offline analysis generated and paper passing which has not affected the design.

The lack of incentive for DoD industry managers to improve the design and manufacturing processes has been the subject of dialogue and discourse for the two decades that I have been closely involved in defense matters. However, there seem to be a collection of forces at work at this time which have broken through the inertia and have created a market for pursuing avenues of major improvement in quality and cost. Much of the credit for this belongs to Bob Costello, the current USD(A) who has made the improvement of design and manufacturing processes his personal campaign over the past two years. Rather than advocating new weapons, he has advocated improved process. During this time, he has started a top-down process including training sessions for senior DoD (including Service managers) in the elements of a strategy for continuous process improvement. He and key Service leaders have met with senior defense industry leaders in prolonged sessions to communicate personally the crucial importance and tremendous leverage which can be had in changing the DoD processes. He has done this using the umbrella "Total Quality Management." I personally see this intense campaign starting to pay off in terms of top level commitment from industry managers. For example, many of the large defense contractors have recently started intensive training programs for their personnel in management methods and techniques which will support their practice of improved processes including concurrent engineering disciplines. (Here I refer to training in multifunction team management disciplines, quality engineering methods, experimental design by such groups as ASI, University of Tennessee productivity center, University of Wisconsin center, Coopers and Lybrand and many others.) In fact, I might note there is a very large business area developing in training.

The results of the concurrent engineering task forces which we have run over the past year and which you will hear later have come along at a time when the market has been created for large scale change.

Thus, when we recently briefed Bob Costello on the results of our concurrent engineering task force efforts, his reaction was that we had outlined the front end or engineering side of his Total Quality approach for DoD. There has been similar positive response from many quarters of defense industry.

In the course of our various task forces, there has been considerable debate over whether advancement in technology is or will be a significant factor in accelerating the widespread application of concurrent engineering in our DoD industries.

Clearly there are a number of success stories where groups have practiced concurrent engineering and achieved remarkable reductions in development schedule and improved quality at the same time using the best existing technology. We need to establish an understanding of the highest leverage areas for DoD sponsored efforts to achieve engineering process improvements on a broad scale. We need to do this for different product areas, technology areas; we need to understand the technology needs for different levels of integration.

Here I am addressing the obvious point that the aircraft people are concerned with structures, surfaces, and integration of subsystems whereas the component supplier is primarily focussed on the interaction of materials, processes, and design.

Over the next year, we plan to have IDA carry on some efforts to put the supporting technology efforts in perspective for different product areas. Without any further analysis, it is clear that the architecture, framework, and product definition areas are crucial to our objectives of accelerating the pace of integration of processes to support concurrent engineering. It strikes me that such integration objectives are not new, but instead become much more clearly focussed through our adoption of concurrent engineering objectives. That is, whereas the Air Force has been supporting CIM programs since the early 1980's and product definition demonstrations since the mid 1980's, the focus has been more on passing design data to manufacturing than on affecting design in a major way through simultaneously designing the manufacturing and support processes as a sanity check on the product design.

Similarly, we have been supporting an industry initiative in accelerating integration of technical data related processes - which we call CALS (Computer-Aided Acquisition and Logistics). Through this we have developed a management structure in DoD and a large industry task force which is evolving specifications for an integrated weapon system product data base. This group already has a task force on "Design Integration." We have recently seen the big aerospace contractors and some information systems contractors form a funded cooperative to accelerate the implementation of PDES (Product Definition Exchange Specifications) with an objective of early demonstrations in 1989. There is a strong commitment from DoD to push future funded efforts of the PDDI, GMAP sort and the NTIS PDES test bed in directions compatible with the industry cooperative recommendations.

It is important to our national effort that the DARPA efforts contribute to and build upon the mainstream that is being formed in the framework and architecture areas. Thus, it will be particularly helpful for this workshop to attempt to clarify and distinguish between what capabilities have been demonstrated or put into practice, what midterm objectives seem feasible, and what longer term goals and research would have high pay off.

I think you have a really excellent program to carry out these important objectives and look forward to working with you.

CONCURRENT ENGINEERING

DEFINITION

AN INTEGRATED PROCESS WHICH ENGINEERS THE PRODUCT AND THE MANUFACTURING AND SUPPORT PROCESSES TOGETHER WITH EMPHASIS ON EFFICIENCY, INCREASED QUALITY AND REDUCED COST.

CONCURRENT ENGINEERING

BACKGROUND

- USD(A) MEMORANDUM — APRIL 1988

- INSTITUTE FOR DEFENSE ANALYSIS   OSD/SERVICES/INDUSTRY
  TASK FORCE   70+ ORGANIZATIONS

- PYMATUNING GROUP   INDUSTRY EXECUTIVES
                                                           20+ COMPANIES

- CALS TASK FORCE ON   TECHNICAL—DOD/INDUSTRY
  DESIGN INTEGRATION   40+ COMPANIES

CONCURRENT ENGINEERING

SELECTED CASE STUDIES

CASE STUDY	COST	SCHEDULE	QUALITY
McDONNELL DOUGLAS	60% SAVINGS ON BID FOR REACTOR AND MISSILE PROJECTS.	SIGNIFICANT SAVINGS (REDUCTION FROM 45 WEEKS TO 8 HOURS) IN ONE PHASE OF HIGH-SPEED VEHICLE PRELIMINARY DESIGN; 18 MONTH SAVING ON TAV-8B DESIGN.	SCRAP REDUCED 58%, REWORK COST REDUCED 29%, AND NON-CONFORMANCES REDUCED 38%; WELD DEFECTS PER UNIT DECREASED 70%; 68% FEWER CHANGES ON REACTOR; 68% FEWER DRAWING CHANGES ON TAV-8B.
BOEING BALLISTIC SYSTEMS DIVISION	REDUCED LABOR RATES BY $28/HOUR; COST SAVINGS 30% BELOW BID.	PART AND MATERIALS LEAD-TIME REDUCED BY 30%; ONE PART OF DESIGN ANALYSIS REDUCED BY OVER 90%.	FLOOR INSPECTION RATIO DECREASED BY OVER 2/3; MATERIAL SHORTAGES REDUCED FROM 12% TO 0; 98% DEFECT-FREE OPERATION.
AT&T	COST OF REPAIR FOR NEW CIRCUIT PACK PRODUCTION CUT AT LEAST 40%.	TOTAL PROCESS TIME REDUCED TO 46% OF BASELINE FOR 5ESS."	DEFECTS REDUCED BY 30% TO 87%.
DEERE & COMPANY	30% ACTUAL SAVINGS IN DEVELOPMENT COST FOR CONSTRUCTION EQUIPMENT.	60% SAVINGS IN DEVELOPMENT TIME.	NUMBER OF INSPECTORS REDUCED BY 2/3.
HEWLETT-PACKARD CO., INSTRUMENT DIVISION	MANUFACTURING COSTS REDUCED 42%.	REDUCED DEVELOPMENT CYCLE TIME 35%.	PRODUCT FIELD FAILURE RATE REDUCED 60%, SCRAP AND REWORK REDUCED 75%.
IBM	PRODUCT DIRECT ASSEMBLY LABOR HOURS REDUCED 45%.	SIGNIFICANT REDUCTION IN LENGTH OF PMT DESIGN CYCLE. 45% REDUCTION IN ELECTRONIC DESIGN CYCLE.	FEWER ENGINEERING CHANGES. GUARANTEED PRODUCIBILITY AND TESTABILITY.

CONCURRENT ENGINEERING

GENERALIZED ELEMENTS

- **TOTAL SYSTEM ENGINEERING — FRAME WORK FOR ENGINEERING PROCESS MANAGEMENT AND INTEGRATED, EXPLICIT DECISION SUPPORT**

- **MULTIDISCIPLINE TEAMS — INTEGRATED PRODUCT AND PROCESS DESIGN, REDUCED NON VALUE ADDED WORK**

- **QUALITY ENGINEERING METHODS — EFFICIENT, EFFECTIVE PRODUCT AND PROCESS OPTIMIZATION**

- **CAD/CAE/CAM — MANAGEMENT OF CHANGE, RAPID TRANSFER OF BENEFITS, REDUCTION OF ERRORS, EFFICIENT DATA COLLECTION AND ANALYSIS, EFFECTIVE INTEGRATION**

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CONCURRENT ENGINEERING

SPECTRUM OF SUPPORTING ACTIVITIES

DoD OBJECTIVES	UNIQUE FUNCTIONS	REQUIRED CAPABILITIES	TECHNICAL BUILDING BLOCKS
	Early, complete & continuing understanding of customer requirements and priorities.	Capture data on comparable products, processes & support (lessons learned).	Data Processing & Data Structures
		Define and capture data for new weapon system product, process & support.	
Reduced Cost		Synthesize requirements into design of product, process & support.	Frameworks/ Architectures
		Validate design of product, process and support.	
Reduced Time	Translation of requirements concurrently and in an integrated fashion into optimal products and manufacturing and support processes.	Manage product, process, and support data.	
		Disseminate product, process, and support data.	Tools & Models
		Deliver product or data for manufacturing & supporting product.	
Increased Quality		Rapid Prototyping	Manufacturing systems
		Process Robustness	
	Continuous review and improvement of product, process & support characteristics.	Intelligent oversight for impact assessment of changes.	
		Proactive availability of current design.	Engineering Processes

CONCURRENT ENGINEERING

- **STRATEGY**
  - IMPLEMENT THROUGH ACQUISITION PROCESS
    "PROCESS EMPHASIS"
  - DOD LEAD THROUGH EXAMPLE
  - INCREASED TECHNOLOGY FOCUS ON TOTAL PROCESS IMPROVEMENT
  - INDUSTRY RESPOND WITH INNOVATION IN PROCESSES

- **CONSIDERATIONS**
  - INDUSTRY WILL ADOPT CONCURRENT ENGINEERING TO ENHANCE COMPETITIVE POSITION
    - IF DOD ENCOURAGES AND ENABLES
    - RECOGNIZES INNOVATION
  - BARRIERS INCLUDE:
    - DOD FRACTIONATION OF REQUIREMENTS
    - TOO LITTLE ATTENTION TO PROCESS
    - TOO MANY "HOW TO" SPECIFICATIONS
    - LACK OF INCENTIVES

9-0271

6

ELEMENTS OF AN ACQUISITION APPROACH

o   INTEGRATED REQUIREMENTS

-   COST, QUALITY AND TECHNICAL

-   INTEGRATED DELIVERABLES

o   DEVELOP SOURCE SELECTION CRITERIA FOR CONCURRENT ENGINEERING

-   PROCESS BASELINE

-   PROCESS IMPROVEMENT RELATED TO COST AND QUALITY

o   DEVELOP MANAGEMENT DISCIPLINE

-   STREAMLINING

-   SYSTEM ENGINEERING INCLUDE "ILLITIES"

-   GOVERNMENT MULTIDISCIPLINE TEAMS

o   PARALLEL MANTECH PROGRAMS INCLUDE CONCURRENT ENGINEERING - START AT CONCEPT PHASE

-   6.2 - 6.3 PILOTS

-   COORDINATED DARPA - SERVICE PROGRAMS

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CONCURRENT ENGINEERING

CURRENT ASSIGNMENTS

- ACQUISITION IMPLEMENTATION   OSD/SERVICES/INDUSTRY ASSOCIATION TASK FORCES

  - INTEGRATED REQUIREMENTS
  - "SYSTEM" ENGINEERING GUIDELINES
  - INTEGRATED CDRLS (CALS)
  - RFP/SOURCE SELECTION

- NEW MANUFACTURING TECHNOLOGY GUIDELINES   OSD/AF/INDUSTRY ASSOCIATION TASK FORCE

- REVISION OF DOD TEMPLATES   OSD/SERVICES/DMB-DSB TASK FORCE

- NEAR TERM EDUCATION/TRAINING   PESO/SERVICES

- LONG TERM EDUCATION/TRAINING   SERVICES/INDUSTRY TASK FORCE

- FOCUSED DOD TECHNOLOGY PROGRAM   IDA/SERVICES TASK FORCE

- INDUSTRY INCENTIVES   PGI

- PILOT PROGRAMS   IDA/SERVICES

- OVERALL STRATEGY   DMB

9-0371

CONCURRENT ENGINEERING

NEEDED USD(A) SUPPORT

- DRAFT USD(A) POLICY AND ASSIGNMENT OF ACTIONS

- INTERACTION WITH CONGRESS

- FUNDING FOR FY 90-91 PILOT PROGRAMS

- BRIEF SECRETARY OF DEFENSE

9-0461

CONCURRENT ENGINEERING

VISION

- REDUCED DEVELOPMENT CYCLE — BY HALF
- ACHIEVES HIGH QUALITY/LOWER COST PRODUCTS
- THROUGH:
    - STREAMLINED PROCESSES
    - MULTIDISCIPLINE TEAMS
    - INTEGRATED DESIGN CF PRODUCT AND PROCESSES
        - PRODUCT/PROCESS OPTIMIZATION
        - PRODUCT DEFINITION
    - PAPERLESS PROCESSES FOR:
        - COMMUNICATION
        - ANALYSIS AND SIMULATION
        - DESIGN RELEASE
        - TRANSFER TO MANUFACTURE
    - RAPID MOCKUPS AND PROTOTYPES

9-0371   10

CONCURRENT ENGINEERING

DOD/INDUSTRY CONCURRENT ENGINEERING TASK FORCE

ELECTRONICS	AIRFRAME	ENGINE	SHIPS
IBM	LOCKHEED	GE	NEWPORT NEWS
TI	BOEING	P&W	
HONEYWELL	GD	GARRETT	
LITTON	GRUMMAN		
GE	BELL		
ITT	NORTHROP		
WESTINGHOUSE	McDONNELL DOUGLAS		
AT&T	HUGHES		
TRW	AEROSPACE		
MCC			
HUGHES			

LAND VEHICLES	MUNITIONS	COLLEGES
GD	AEROJET	HARVARD
JOHN DEERE		MIT
FORD		CARNEGIE MELLON
		PRINCETON
		RPI
		UNIV OF MARYLAND
		UNIV OF WISCONSIN
		UNIV OF IOWA
		UNIV OF RHODE ISLAND

CALS TASK FORCE ON DESIGN INTEGRATION
ELECTRONICS

PRIME CONTRACTORS	ELECTRONICS CONTRACTORS	CONSULTANTS & UNIVERSITIES	GOVERNMENT
MCDONNELL AIRCRAFT	LOCKHEED-ELECTRONICS	VIRGINIA TECH	OASD
RAYTHEON	HARRIS	UNIV OF MARYLAND	NOSC
BOEING AEROSPACE	TEXAS INSTRUMENTS	SIEGFRIED ENT	USAF
MARTIN MARIETTA	ROCKWELL COLLINS	SIGMA PLUS	AFHRL
LOCKHEED-GEORGIA	WESTINGHOUSE	MCC	
NORTHROP	LITTON AMECOM	DACOM	
GENERAL DYNAMICS	GOULD	PCA	
ROCKWELL INTERNATIONAL	SANDERS	GIORDANO	
HONEYWELL	UNISYS	VEDA	
TRW	IBM		
	AT&T		

9-0491

CONCURRENT ENGINEERING

CALS TASK FORCE ON DESIGN INTEGRATION
MECHANICAL SYSTEMS

CONTRACTORS	CONSULTANTS UNIVERSITIES	GOVERNMENT
ALLIED-SIGNAL AEROSPACE	ADVANCED TECHNOLOGY	AF HUMAN RESOURCES LAB
ALLISON GAS TURBINE DIV. G.M.	D. APPLETON COMPANY	ARMY ARMEMENT R&D CENTER
AUTOMATED IMAGES	INTERGRAPH	DOD PROD. ENG. SERVICES OFFICE
AVONDALE SHIPBUILDING	MANAGEMENT SCIENCES	NAVSEA
BMY CORPORATION	PROSPECTIVE COMPUTER ANALYSTS	NAVAL AVIATION DEPOT
BATH IRON WORKS	SIGMA PLUS	OASD (P&L) CALS
BELL HELICOPTER TEXTRON	STRUCTURAL DYNAMICS RESEARCH CORP.	US ARMY MAN ENG. COLLEGE
CADILLAC GAGE TEXTRON	W. G. BEAZLEY ASSOCIATION	
CONTROL DATA CORPORATION	UNIVERSITY OF IOWA	
FMC GROUND SYSTEMS	UNIVERSITY OF NEW MEXICO	
GE AIRCRAFT ENGINES		
GD LAND SYSTEMS, FT. WORTH		
GRUMMAN AIRCRAFT SYSTEMS		
IBM		
LOCKHEED AERO SYSTEMS		
MCDONNELL AIRCRAFT, HELICOPTER		
NEWPORT NEWS SHIPBUILDING		
PRATT & WHITNEY		
ROCKWELL INTERNATIONAL		
SARGETN CONTROLS		
SIKORSKY AIRCRAFT		
SPERRY MARINE, INC.		
WESTINGHOUSE ELECTRONICS		
YORK INTERNATIONAL		

OVERVIEW

o DEFINITION

o BACKGROUND

o EXAMPLES

o KEY FEATURES

o IMPLEMENTATION ELEMENTS

o SUMMARY

CONCURRENT ENGINEERING

PYMATUNING GROUP EXECUTIVE TASK FORCE

AIRCRAFT	ELECTRONICS	OTHER
BOEING	HUGHES AIRCRAFT	AEROJET
GENERAL DYMANICS	HUGHES RADAR	BATTELLE
GRUMMAN	IBM FEDERAL SYSTEMS	DRAPER LABS
LOCKHEED	IBM COMPUTERS	IDA
MCDONNELL DOUGLAS	ITT	IITRI
NORTHROP	WESTINGHOUSE ELECTRONIC SYSTEMS	SAIC
	WESTINGHOUSE DEFENSE RADAR	SRI

"INDUSTRIAL INSIGHTS ON THE DOD CONCURRENT

ENGINEERING PROGRAM"

THE PYMATUNING GROUP

<u>INDUSTRIAL INSIGHTS</u>

<u>ON THE</u>

<u>DOD CONCURRENT ENGINEERING</u>

<u>PROGRAM</u>

The Pymatuning Group, Inc.
OCTOBER 1988

E. J. ISTVAN
PEI 881207

CONCURRENT ENGINEERING -

WHY NOW?

<u>- HISTORICAL SHIFT -</u>

<u>WWII</u>	<u>LAST 20 YEARS</u>
- Focus on "<u>outproducing</u> and outperforming" adversaries	- Focus on "<u>Qualitative</u> Superiority" over adversaries
- Hi-volume, utilitarian products	- Hi-sophistication, small volume products
- "Triumph of Manufacturing" in U. S.	- Manufacturing Process Technology lagging in U. S.
- Defense Production based upon civilian market production capabilities	- Defense production increasingly unrelated to civilian market production capabilities

CONCURRENT ENGINEERING

○   Integral to Quality Management

○   Closely coupled to "CALS"

"One aspect which adds greatly to the complexity of modern weapons
system development, is that the contractor teams comprise many individual
companies, of varying sizes and locations, and that the definition of the
product and the processes used to build and maintain the weapons system are
performed in a number of widely-distributed locations."

CONCURRENT ENGINEERING

- PGI APPROACH -

o   Implementation principally in industry with industry investments

o   Need for dialog between DoD and its defense industry

    The needed industry insights on how best to introduce and
    implement Concurrent Engineering practices are so important
    to OSD/USD(A) at this formative stage of the Program, that
    The Pymatuning Group was asked by DASD(P&L)/ADASD (Systems)
    to employ a quick-reaction mechanism that would stimulate
    industry response and expedite its influence on the Program.

o   Informal quick-reaction mechanism put into place:

    - The DoD Industrial Concurrent Engineering Strategy Forum

SPECTRUM OF INDUSTRIAL PARTICIPATION

Boeing	Aerospace	Battelle
General Dynamics	Hughes Radar	Draper
Grumman	IBM	IDA
Hughes Aircraft	ITT	IITRI
Lockheed	Westinghouse	PGI
McDonnell Douglas	Sarnoff Research Center	SAIC
Northrop		

MAJOR FINDING

The major finding by the Forum is that Concurrent Engineering is a sound concept, that it has benefitted both the customers and the producing industries where applied, that it can and has yielded major reductions in cost and development time for modest up-front investments, and that it makes good sense to encourage the application of Concurrent Engineering practices and methodologies throughout all industrial organizations supplying the Department of Defense.

FINDING: THE PROCUREMENT FUNDING NEEDS ADJUSTMENT

The use of concurrent engineering practices early in the design process will skew the traditional procurement funding profile by greater up-front loading of costs. At the same time, experience shows that potential savings in life cycle product costs from improved reliability, supportability, etc. more than offset the higher initial cost.

An exemplary key recommendation in the Forum Report is that:

"A parallel funding "line" for manufacturing innovations, e.g., concurrent engineering practices, should accompany each procurement request for sophisticated, novel or complex products. This will allow for "manufacturing process" funding to track along with all appropriate product development contracts and should help DoD in its innovative production "catch-up" posture."

7

FINDING: CONTRACTOR/DOD SHARING OF C/E SAVINGS

MUST BE MADE INTEGRAL TO PRODUCTION CONTRACTS

FINDING: LARGE SCALE EDUCATION OF BOTH GOVERNMENT
AND INDUSTRY PERSONNEL IS NEEDED.

FINDING: THE PROCESS FOR GENERATING, AND PROCEDURES
FOR EXPRESSING AND SPECIFYING REQUIREMENTS MUST BE
ADJUSTED TO FACILITATE THE INTRODUCTION AND EMPLOYMENT
OF C/E PRACTICES

(October 24, 1988)

• Concurrent Engineering is the most powerful single means for making Total Quality Management (TQM) succeed in industry and DoD

• The technologies that comprise Concurrent Engineering are available and used by major defense primes and some subtier suppliers

• However, the deployment of Concurrent Engineering technologies is not necessarily occurring at the pace or to the extent needed by DoD

   ... Very little data available ... Case studies do not tell the story

   ... Priorities accorded deployment and occurrence are still primarily those of industry, not of DoD

• Concurrent Engineering will not occur without changes in management structure and approach (culture) in industry

   ... Technology alone will not make it

• Only DoD as a "Monopolistic" customer can accelerate the pace, the extent, and the occurrence of Concurrent Engineering in the Defense Industrial Base

   ... A significant portion of the near term actions necessary must be undertaken by DoD

   ... There is ample evidence that continuation of current acquisition practices will not suffice

• Some key changes must be made by DoD in:

   ... The Requirements Definition Process which presently prohibits the continuous improvement in product and process which is the hallmark of Concurrent Engineering

   ... Contractual funding arrangements which currently do not provide for supplemental funding consistent with the accelerated use of Concurrent Engineering by contractors. This supplemental funding is perhaps the best way to achieve:

   –   Risk-sharing by DoD, and

   –   Benefit sharing by industry

   ... Program Management to put in place the DoD counterpart to industry's System Engineer – an essential component of Concurrent Engineering. The DoD counterpart for each program would be named Lead Program Executive and he would have the authority:

   –   To lead the DoD team throughout the Program life,

   –   To make trade-offs and determine acceptable risks,

   –   To be the lead contact with industry,

   –   To instil the best of the much admired "Skunk Works" approach, and

   –   To effect the team approach which epitomizes Concurrent Engineering

2

● DoD should take the lead in obtaining legislation for "Manufacturing Engineering" equivalent to the National Defense Education Act of 1958

● The current state of understanding and awareness of Concurrent Engineering in DoD mitigates against the needed pace of change within DoD

● The needed understanding and awareness of Concurrent Engineering within Industry as a whole is probably inadequate to achieve the needed pace of change within the Defense Industrial Base

   ... DoD must state more forcefully its changing policies, practices, and schedules

5

● As a cautionary note, DoD policy officials should exert extraordinary controls in the near term to prevent inappropriate introduction into contracts of Concurrent Engineering requirements. There is already evidence of such occurrences which are properly causing negative reactions from industry management

4

REPORT CARD ON CONCURRENT ENGINEERING TODAY:
(October 1988)

- Active interest and participation by major Defense Prime contractors

- Awareness steadily increasing in Defense Industrial Base

- Actual use by industry is fragmentary

- Supported by OSD/DoD Senior Policy Officials

- Awareness spotty to non-existent in DoD PMO and contracting communities

- Confusion concerning relationship among various USD(A) initiatives, e.g., TQM and Concurrent Engineering

- No supporting contractual, funding, or acquisition changes evident

- Congressional awareness/support uncertain

- A few Weapons Systems Programs are already using or are actively considering the use of Concurrent Engineering, e.g., ATF, ALS, mobile launcher, LHX, etc.

- AF Variability Reduction Program includes Simultaneous (i.e., Concurrent) Engineering objectives

PRINCIPAL RECOMMENDATIONS

The Forum recommends that the Department of Defense:

1. Develop policies and procedures to actively encourage, but not mandate, the implementation of Concurrent Engineering practices by the Defense Industrial Base.

2. Explicitly acknowledge Concurrent Engineering as a principal means for achieving the Department's Total Quality Management (TQM) objectives.

3. Establish a "Concurrent Engineering Initiative" to provide funds for education and research to accelerate the adoption and advancement of Concurrent Engineering practices and methodologies.

4. Create a Requirements Development, Request for Proposals (RFP), and Acquisition process which provides greater latitude for on-going trade-offs of system requirements.

"THE ROLE OF CONCURRENT ENGINEERING IN WEAPONS SYSTEM ACQUISITION"

THE INSTITUTE FOR DEFENSE ANALYSIS

Concurrent Engineering in Weapons System Acquisitions

Phase I: Briefing to DARPA Workshop

Dr. Robert I. Winner
Institute for Defense Analyses
Computer and Software Engineering Division

- Definition of Concurrent Engineering

- Key Elements of Concurrent Engineering

- Examples of use

- Conceptual Framework

- Recommendations in Phase I Report

Definition of Concurrent Engineering

Concurrent engineering is a systematic approach to the integrated, concurrent design of

— products and

— their related processes including manufacture and support.

This approach is intended to cause the developers, *from the outset* to consider all elements of the life cycle from conception through disposal, including

— quality,

— cost,

— schedule, and

— user requirements.

IDA

- **Goal:** *simultaneously* increase quality, decrease cost, decrease schedule

- Concurrent engineering succeeds because it forces the designers to try to optimize over a broader scope which includes the downstream processes.

- We have found U.S. companies doing parts of concurrent engineering but not all. Some working at the system level, some at the detailed part and process optimization level. Examples of each follow.

4

Key Elements I

IDA

- Getting downstream information upstream to be used
    - Humans in a team
    - Data, object, and knowledge bases
    - Design rule tools
    - Improved requirements capture
- Getting upstream processes integrated
    - Team culture and its support
    - Integrated CAD/CAE/CAM/CALS
    - Integrated tracking of requirements/features/processes
    - Tools and methods that facilitate process design

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● **Decreasing the number, cost, and time of design cycles/Problem prevention**
  - **Better control of prototyping**
  - **Simulation and soft prototyping of products and processes**
  - **Statistical methods tying design to downstream processes**
  - **Flexible manufacturing**

Study Basis

Based on Success Stories Plus

● Difficulties Encountered

● Barriers
  - Organizational
  - Technical

● Expert Opinion

● Our Judgement

IDA

- Engineering Process Initiatives

- Computer-Based Support Initiatives

- Formal Methods

Types of Results

IDA

- Quality Improvements
    - Consistency/Reduction of Variability
    - Defect Count Reduction
    - Engineering Change Reduction
    - Inspection Reduction
    - Rework Reduction
    - Field Failure Rate Reduction

- **Cost Reduction**
  - Reduced Bids
  - Reduced Design Cost
    - Number of Passes: Down
    - Computer Support for Information Tracking
  - Reduced Fabrication, Manufacture, Assembly
    - Labor Rates/Costs: Down
    - Part Counts: Down
    - Inventory: Down
  - Reduced Scrap/Rework Costs

Types of Results—3

- **Decreased Development Cycles**
  - Total Process Time
  - Parts/Materials Lead Times
  - Component Design
  - System Design

Example: John Deere, Dubuque

IDA

- Example scope: customized system
- Overly complex design and production system
  - award winning but slow and costly
  - Deere became non-competitive.
- Implemented: just-in-time, integrated automation, multidiscipline teams, flexible manufacturing, benchmarking of competitive products
- Pervasive cultural change required
  - Upper management committment and involvement
  - Supported by unionized labor
- Manufacturing concerns integrated with product design with flexible manufacturing allowing delayed design freezes.
- System for feedback from field users into ongoing design and manufacturing process.
- Hardcopy drawings almost completely eliminated allowed by sophisticated internetworking of CAD, CAE, CAM, business systems.

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Deere Results

IDA

- Development time reduced 60% (from 7 years) with associated cost savings of 30%

- Engineering builds reduced to 1 (from 4)

- Parts fabrication and inventory reduced 65%

- Inspectors reduced 66%

- Field surveys indicate 100% increase in service life

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- Example scope: detailed part and process optimization.

- GOCO Plant under control but 19/25 40K lots rejected

- Tiger team fails to solve problem in 1 year

- Aerojet asked to help

- Design/Process parameter optimization via well-designed experiments led to 100% yield

Other Examples

- IBM reduced development time and cost very significantly on recent mainframe via multidiscipline team and integrated CAD/CAM. The system is more evolvable and customizable at lower cost in less time.

- ATT used organizational and process changes including CAD standardization, simulation, prototyping on the manufacturing line, and others to very significantly reduce the number of circuit pack design cycles from 3 to 2 and heading toward 1. First-pass yields rose from 50% to 90%.

- ITT used statistical methods for the optimization of design and production process parameters on night vision goggles to achieve very significant increases in the expected life of the product. Similar results were achieved in travelling wave tube design. Illustrates that there are techniques that help us deal with ill-understood technologies during product design.

IDA

- Characteristics of Successful Companies

- Differences of Approach

- Details of Existing Methods and Technologies

- Misconceptions about Concurrent Engineering

- Pitfall Stories

- Conceptual Framework (In This Briefing)

- Recommendations (In This Briefing)

16
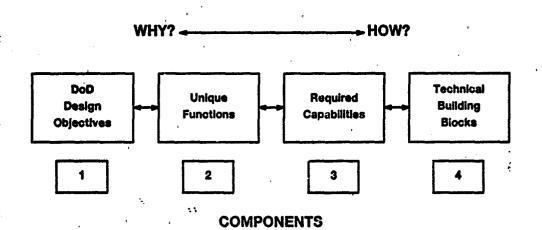
A CONCEPTUAL FRAMEWORK FOR C.E.

IDA

- **Purpose: understanding and programmatic planning**

- **Users: researchers, developers, sponsors, practitioners**

- **Structure: four components showing how/why relaticnships**

- **Bottom line: technical building blocks**

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WHY? ←———————————→ HOW?

DoD Design Objectives	Unique Functions	Required Capabilities	Technical Building Blocks
1	2	3	4

COMPONENTS

FOUR COMPONENTS DETAILED

COMP 1	COMP 2	COMP 3	COMP 4
DoD OBJECTIVES	UNIQUE FUNCTIONS	REQUIRED CAPABILITIES	TECHNICAL BUILDING BLOCKS
	Early, complete & continuing understanding of customer requirements and priorities.	Capture data on comparable products, processes & support (lessons learned). Define and capture data for new weapon system product, process & support.	Data Processing & Data Structures
Reduced Cost		Synthesize requirements into design of product, process & support.	Frameworks/ Architectures
		Validate design of product, process and support.	
Reduced Time	Translation of requirements concurrently and in an integrated fashion into optimal products and manufacturing and support processes.	Manage product, process, and support data. Disseminate product, process, and support data. Deliver product & data for manufacturing & supporting product.	Tools & Models
Increased Quality		Rapid Prototyping Process Robustness	Manufacturing systems
	Continuous review and improvement of product, process & support characteristics.	Intelligent oversight for impact assessment of changes. Proactive availability of current design.	Design Processes

WHY? ◄───────────────► HOW?

DoD Design Objectives	Unique Functions	Required Capabilities	Technical Building Blocks
1	2	3	4

COMPONENTS

DOD DESIGN OBJECTIVES

IDA

- Lower Cost

- Reduced Time

- Increased Quality

WHY? ←————————————→ HOW?

DoD Design Objectives	Unique Functions	Required Capabilities	Technical Building Blocks
1	2	3	4

COMPONENTS

REQUIRED UNIQUE FUNCTIONS

● **Timing:** Early, Complete, and Continuing Understanding of Customer Requirements and Priorities

● **Process:** Translation of Requirements Concurrently and in Integrated Fashion into Definitions of Product and Manufacturing and Support Processes

● **Philosophy:** Continuous Review and Improvement of Product, Process, and Support

IDA

- Design Must Be By Integrated, Continuing Multifunction Team.

- Multifunction Process Must Provide Efficient Iteration and Closure.

- Process Must Identify, Analyze, and Resolve Conflicting Requirements.

- Process Must Incorporate Optimization of Product and Process Design.

UNIQUE FUNCTIONS III: PHILOSOPHY

IDA
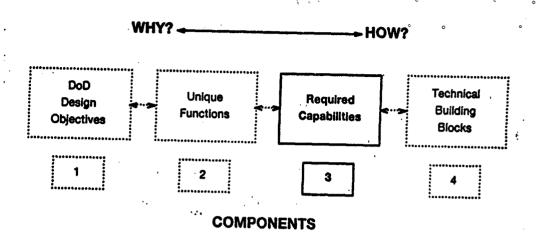
Must Have...

- Open and Continuous Customer/Vendor Communication

- Development of Complete, Unambiguous Statement of Requirements
  — Probably Evolved Through Concurrent Engineering Process

- Baseline Product and Process Evaluation

WHY? ◄─────────────► HOW?

DoD Design Objectives		Unique Functions		Required Capabilities		Technical Building Blocks
1		2		3		4

COMPONENTS
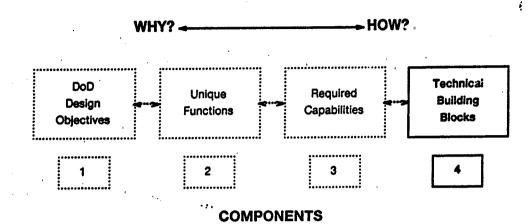
REQUIRED CAPABILITIES

● Data Definition and Capture: Historical & New Data & Knowledge

● Design Synthesis, Tradeoff, and Validation: Increasing Efficiency

● Information Management, Dissemination, and Delivery: Evolvable, Tailorable, Interoperable, Secure, Distributed, High-performance Info Management Systems

● Rapid Representative Prototyping: Improve Design/Manufacturing Linkage

● Process Robustness: Against Design Changes, Process Drift, External Factors (Noise)

WHY? ◄──────────► HOW?

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┌ ─ ─ ─ ─ ─┐       ┌ ─ ─ ─ ─ ─┐       ┌ ─ ─ ─ ─ ─┐       ┌──────────┐
┊   DoD    ┊       ┊          ┊       ┊          ┊       │ Technical│
┊  Design  ┊◄─ ─ ─►┊  Unique  ┊◄─ ─ ─►┊ Required ┊◄─ ─ ─►│ Building │
┊Objectives┊       ┊ Functions┊       ┊Capabilities┊     │  Blocks  │
└ ─ ─ ─ ─ ─┘       └ ─ ─ ─ ─ ─┘       └ ─ ─ ─ ─ ─┘       └──────────┘

┌ ─ ─ ─ ─┐         ┌ ─ ─ ─ ─┐         ┌ ─ ─ ─ ─┐         ┌────────┐
┊   1    ┊         ┊   2    ┊         ┊   3    ┊         │   4    │
└ ─ ─ ─ ─┘         └ ─ ─ ─ ─┘         └ ─ ─ ─ ─┘         └────────┘
```

COMPONENTS

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TECHNICAL BUILDING BLOCKS: AREAS IDA

- **Data**

- **Information Frameworks**

- **Tools and Models**

- **Manufacturing Systems**

- **Design Processes**

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COMPONENT 4: DATA

- Operational and support processes and environments data

- Design process data

- Manufacturing process data

- Information architecture (model)

COMPONENT 4: INFORMATION FRAMEWORKS

- Enterprise information management system (including information architecture)

- Requirements, specification, design and description languages

- Requirements and specifications metrics

- Simulation framework (including analysis of results)

- Information distribution system

- Product, process, performance and support models

- Assembly models

- Solid models

- Cost models

- Tools for analysis of simulations

- Design rules that integrate performance and all the 'ilities

- Problem identification and solution techniques

- High Performance computers

COMPONENT 4: MANUFACTURING SYSTEMS

- Integration of design systems and manufacturing cells

- Production process technologies

● **Design team dynamics**

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Recommendations

- Top-Down Implementation—encourage accelerated deployment

- Executive-level commitment—implementation mechanism for TQM

- Build onto existing programs—DoD, national, state, and private

- Education and training—throughout acquisition chain (esp. top)

- Method and technology development—data, information frameworks, tools and models, manufacturing processes, etc.

- Pilot projects—identify better deployment, key product technology issues, barriers

- Address barriers—cultural, technical, administrative, legislative

35

IDA

- There is tremendous potential for concurrent engineering in weapons system acquisitions.
  - Marriage of quality engineering techniques with integrated, computer aided engineering and manufacturing

- Concurrent engineering entails a pervasive change in the way of doing engineering and production.

- Concurrent engineering is based on bringing the maximum amount of information and knowledge to bear on engineering decisions. This includes information and knowledge on the design, production, use, evolution, and maintenance of the product.

- Concurrent engineering starts with the requirements generation process. Requirements are generated by a dialogue between the users and the designers; this dialogue continues through the initial design phase so that intelligent trade-offs can be made among cost, schedule, performance, reliability, maintainability, etc.

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General Observations II

IDA

- Concurrent engineering depends on the use of multidiscipline teams with responsibility and authority for product design and production.

- Issue: Should DoD review its policies and practices with a view toward integration, flexibility, and applicability to the concurrent engineering of weapons systems?

- Industry has started; we are looking to deploy on a broader scale. Industry is going to do most of the implementing without the government specifying how. How far should the DoD go in enabling and encouraging the deployment of C.E.?

- What DoD and its industries really need is a committment and implementation of sustained improvement to the engineering and manufacturing process. Concurrent engineering is simply a first step.

37.

DARPA-ISTO

B-7

DARPA/ ISTO MANUFACTURING PROGRAM

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SOME ISSUES

- View of strategic issues has been evolving
  - Speed of design and product deployment
    - — to accelerate experimentation with new product functions
  - Die production is crucial technical issue in mass manufacture
  - Central role of modeling and metrology: control all steps of the manufacturing process to guarantee quality
  - CIM for early trouble warning and factory control
  - Comprehensive view of all factory processes for manufacturing process design
  - New technologies (e.g., composites) which can revolutionize product technical design in some cases
- Issue still to be faced: "non-touch costs"

INTENDED RESULTS

- **Facilities for rapid physical prototyping of piece parts and assemblies.**

- **Family of machine tools with leap-ahead technology featuring next generation controllers and world-class reliability.**

- **Means for comprehensive real-time dynamic simulation of manufacturing processes and products, plus laboratory verification.**

- **"Special opportunity" systems; e.g. fabrication and inspection of composites.**

ADDITIONAL RATIONALE

- **Key U.S. industries losing viability — intense international competitive pressures.**

    DANGER OF EXTINCTION: U.S. piece-parts manufacturers 80 to 90 percent dependent upon foreign competitors for machine tools. The ISTO program and DARPA's leadership could help provide U.S. produced leap-ahead products in 4 to 6 years.

- **Well-controlled processes vital for reliable and cost effective production.**

    Results of laboratory research efforts to be applied to total factory setting.

- **Strong consumer electronics market KEY to the health of defense electronics.**

    The ability to rapidly explore the largest possible variety of new products is essential in this and other manufacturing areas.

- **ISTO's programs must aim at faster product realization and evaluation of reliable products.**

CURRENT AND PROSPECTIVE ISTO MANUFACTURING PROGRAM

- **Current research focus**
  - CAD/CAM for mechanical parts and assemblies
  - Comprehensive modeling of dynamic physical systems
  - New manufacturing technologies
    - stereolithography for rapid prototyping of dies
    - Robotic layup and inspection of composite materials
    - Computer-aided tools for process control

- **New opportunities have been identified in three areas:**
  - Machine tools: integrate advanced design/analysis system and metrology with tool control
  - Rapid product realization and end-user tests for small electronic systems
  - Factory C^3 for process metrology and control

Manufacturing Program Plan

INTEGRATED PRODUCT AND PROCESS DESIGN FOR MECHANICAL PARTS AND ASSEMBLIES
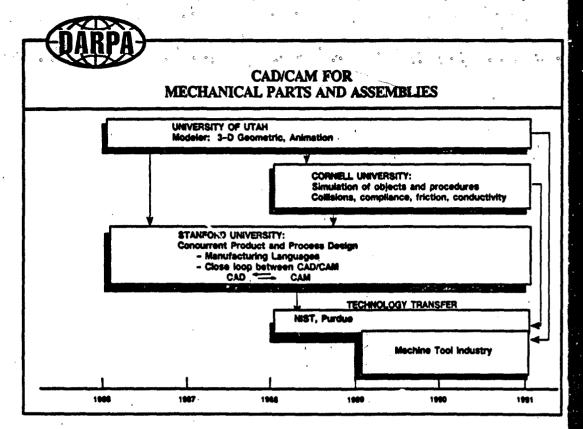
OBJECTIVE: To bridge the gap between design and manufacturing in an implementation that supports simultaneous engineering, team design and rapid prototyping.

Implementation

Designer programs manufacturing "languages"

- Machining
- Injection molding
- Assembly

Machining operators: "hole," "pocket," "sweep"

Assembly operators: "attach," "insert," "align"

Sweep operators: direct control of simulated tools

Solid modeler: incrementally simulates plan

Completed plans: compiled into NC-Code

Physical part: milling machine, assembly robot

**CAD/CAM FOR
MECHANICAL PARTS AND ASSEMBLIES**

UNIVERSITY OF UTAH
Modeler: 3-D Geometric, Animation

CORNELL UNIVERSITY:
Simulation of objects and procedures
Collisions, compliance, friction, conductivity

STANFORD UNIVERSITY:
Concurrent Product and Process Design
- Manufacturing Languages
- Close loop between CAD/CAM
CAD ⇌ CAM

TECHNOLOGY TRANSFER
NIST, Purdue

Machine Tool Industry

| 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |

RESULTS: STANFORD UNIVERSITY

FIRST CUT PROJECT

• An improved machining knowledge base with additional operations and features

• An ability to monitor processing conditions (e.g., forces, vibrations) while making prototypes

• An ability to run First-Cut simultaneously on several workstations

• A preliminary knowledge base and user interface for an "assembly mode" in which designers can design assemblies of parts for robotic assembly (the demonstration also featured a very limited capability to automatically generate instructions for Adept One robot, which accomplished the assembly)

• A preliminary knowledge base for an "injection molding mode" and an interface to a commercial CAD system from Computervision Inc.
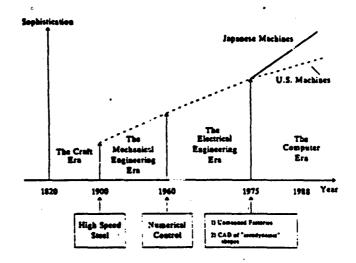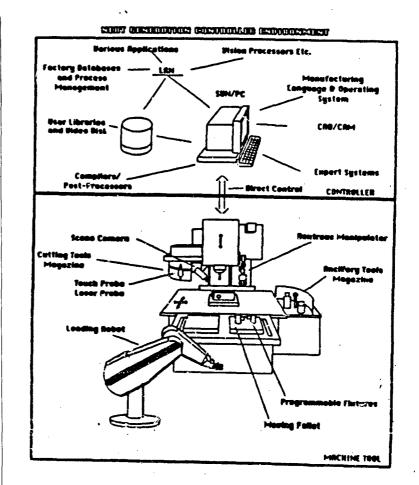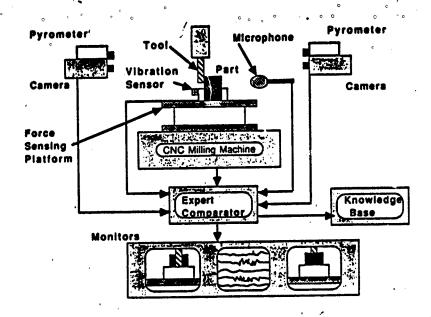
Figure 2. The four eras of the machine tool industry

Pyrometer · Tool · Microphone · Pyrometer

Camera · Vibration Sensor · Part · Camera

Force Sensing Platform

CNC Milling Machine

Expert Comparator · Knowledge Base

Monitors

RESULTS: CORNELL UNIVERSITY
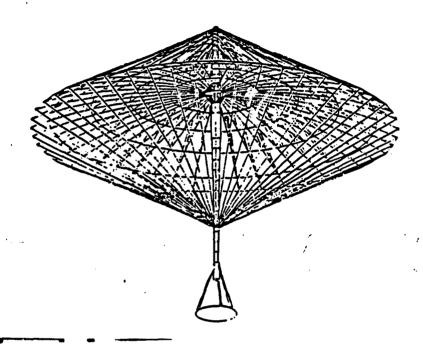
A new paradigm for improving robustness of engineering computations.

Inherent Problems:

–Engineering algorithms fail when multiple conversions of floating point data to symbolic data are made in an inconsistent fashion.

–Double precision does not solve the problem it only hides the difficulty.

Research Results:

–Demonstrated that code for important problems such as the intersection of a convex polyhedra can be structured so that all conversions of numeric to symbolic data are independent.

–Achieved several orders of magnitude improvement in robustness for code that intersects polyhedra.

Important implications for next generation of solid modelers.

DARPA

FAST PRODUCTION OF DIES AND MOLDS
SHAPE BY DEPOSITION

Stamping or molding can shape materials at low cost

- Manufacturing the initial die is expensive

Task: Reduce cost of dies and molds by incremental material build-up technologies

- Stereolithography (CMU)
  - Developed by 3-D Systems, Inc.
  - Device testing stage at several companies
  - Scanning laser and vat-platform assembly
  - Can be coupled to 3-D modeling system
  - Piece parts and forms for dies or molds
- Plasma Spraying (CMU)
  - High performance coatings onto near net shape parts
    Dies, forging preforms, moving parts, rollers, etc.
- Selective Laser Sintering - under review
  (developed by University of Texas at Austin)

DARPA

Summary of Current Efforts

Themes:

Advanced CAD tools and their integration into machining and forming practice

Rapid prototyping of electronic and mechanical systems

Improved production reliability and process control

Stanford

Simultaneous of product and process for machining and injection molding

Utah

Geometric object description for machining

Purdue (w. NSF)

Quick prototyping of mechanical parts; automated assembly technology

Cornell

Geometric and dynamic simulation of manufacturing processes

National Institute of Standards and Technology

CMU

Manufacturing research testbed

SRI

Fast object prototyping by stereolithography and plasma spraying

Automated layup and inspection of composites

DARPA

Summary of Current Efforts, Cont'd.

THEMES:

ADVANCED CAD TOOLS AND THEIR INTEGRATION INTO MACHINING AND FORMING PRACTICE

RAPID PROTOTYPING OF ELECTRONIC AND MECHANICAL SYSTEMS

IMPROVED PRODUCTION RELIABILITY AND PROCESS CONTROL

Lockheed

Expert Systems and case-based reasoning for manufacturing system breakdown diagnosis

U. Arizona/IBM

Collaboration technology for evaluating manufacturing group work processes and non-touch cos factors

BAA

Integration of CAD and measurement tools into machining environment

BAA

Fast prototyping of molds and dies

BAA

Product-level packaging systems for rapid prototyping of electronic systems

DARPA

ISTO MANUFACTURING PROGRAM
Administrative Milestones

	FY88	FY89	FY90	FY91

CAD/CAM Mechanical Parts

Initiated

Technical Review

Industrial Liaison

New Machine Tool Environment

BAA

Contracts

Fast Production of Dies
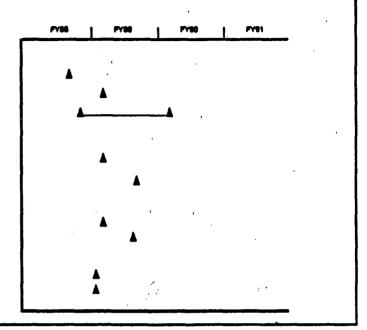
BAA

Contracts

Special Opportunities

Composites

Stereolithography

DARPA

ISTO MANUFACTURING PROGRAM
Technical Road Map

	FY88	FY89	FY90	FY91

Concurrent Product & Process Design

Simple Milling
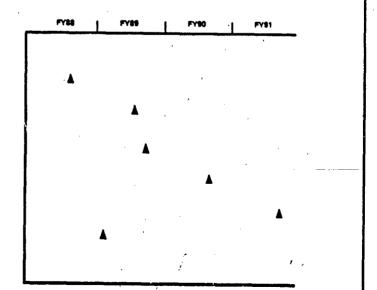
CNC Machining at ME1203 Level

Assembly of Two Machined Parts

Modeling of Electromechanical Systems
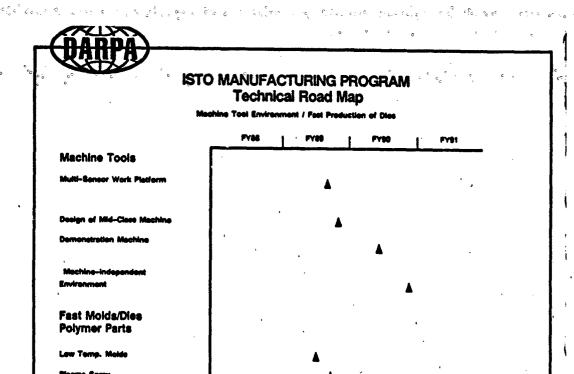
Assembly of Robotic Car

Robust Algorithm for Geometric Modeler

DARPA

ISTO MANUFACTURING PROGRAM
Technical Road Map
Machine Tool Environment / Fast Production of Dies

	FY88	FY89	FY90	FY91

Machine Tools

Multi-Sensor Work Platform

Design of Mid-Class Machine

Demonstration Machine

Machine-Independent
Environment

**Fast Molds/Dies
Polymer Parts**

Low Temp. Molds

Plasma Spray

later1

14 Oct 88

[1]

ISTO MANUFACTURING PROGRAM
Technical Road Map
(Robotics For Composites)

	FY88	FY89	FY90	FY91

**Composite Layup
And Inspection**

Preliminary Study Complete

State-of-Art Survey

Workshop

Assessment of Current
Automated Processes

Phase II Decision

later1

14 Oct 88

[0]

AFWAL MANUFACTURING TECH DIRECTORATE INITIATIVE

IN CONCURRENT ENGINEERING

Air Force Manufacturing Technology Directorate

Concurrent Engineering

AFWAL

Manufacturing Technology Directorate

Initiatives

in

Concurrent Engineering

Gerald Shumaker

AFWAL/MTC
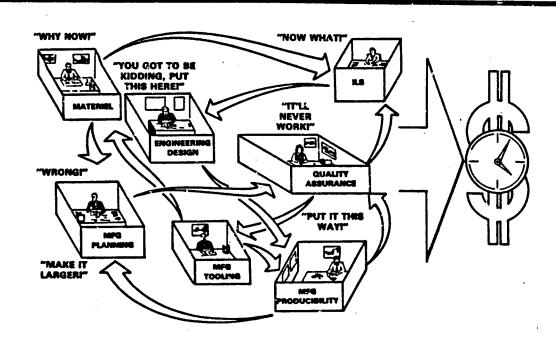
513-255-6976

DARPA CD/CE Workshop
6-8 Dec, 1988

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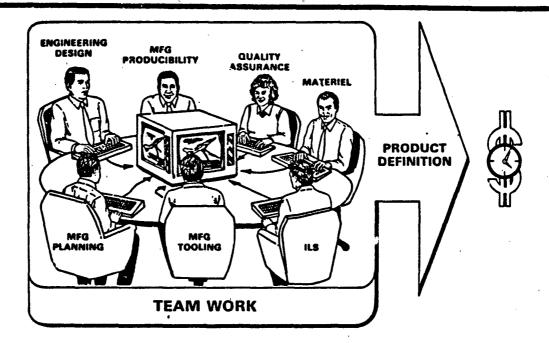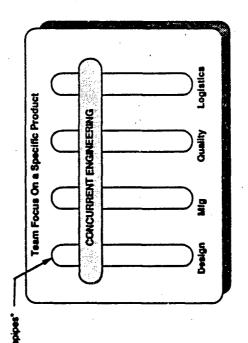
SERIAL PRODUCT DEVELOPMENT

CONCURRENT ENGINEERING

ENGINEERING DESIGN · MFG PRODUCIBILITY · QUALITY ASSURANCE · MATERIEL · MFG PLANNING · MFG TOOLING · ILS

PRODUCT DEFINITION

TEAM WORK

Team Focus On a Specific Product

CONCURRENT ENGINEERING

Design · Mfg · Quality · Logistics

Concurrent Engineering Cuts Across Many Disciplines

"Stovepipes"

Air Force Manufacturing Technology Directorate

Concurrent Engineering

Elements of Concurrent Engineering

- **Improved Management/Cultural/Business Practices**

- **Application of Systems Engineering Process**
  Eg; QFD, Taguchi, Architectures, Information & Process Modeling

- **Computer "Power", Supporting Tools & Integration of Systems**

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> **6-8 Dec, 1988**

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Concurrent Engineering

CEO FOCUS

- **PEOPLE ORIENTED**
  - People communicating & sharing information
  - Computers used as an extension of the way they do their job
  - Goal is to make computers helpful to this process

- **TRAINING, CULTURE, BUSINESS APPROACH & CONTRACT INCENTIVES MUST BE CONSIDERED**

- **NEAR TERM PILOT PROGRAMS & DEMONSTRATIONS ESSENTIAL TO BETTER UNDERSTAND IMPLEMENTATION STRATEGIES & GAIN SUCCESS**

- **ESTABLISHMENT OF THE PROCESS (Long Term) IS AS IMPORTANT AS THE PILOTS & DEMO'S**

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> **6-8 Dec, 1988**

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END OBJECTIVE

- **HELP THE AIR FORCE BUY & SUPPORT WEAPON SYSTEMS MORE EFFICIENTLY**

- **HELP INCREASE THE COMPETITIVENESS OF U.S. WEAPON SYSTEM MANUFACTURERS & SUPPORTING INDUSTRIAL BASE**

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CEO STRATEGY

- Orchestrate & Focus Center - Wide Activities in CE
- Guide & Leverage Product Division CE Initiatives
  - -- Complement R & M 2000 & TQM Initiatives
- Conduct/Manage R & D programs where work is needed
  (Not already in an existing mission area)
    - -- Contractual
    - -- In House (possible)
- Advocate Role for the Above

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Concurrent Engineering

OVERALL PROGRAM DEVELOPMENT STRATEGY

```
┌─────────────────────────┐
│ Near Term Demo's        │
└─────────────────────────┘
            │
            ▼
┌──────────────────────────────────┐
│ Midterm Development (6.2/6.3/7.8) │
└──────────────────────────────────┘
            │              │
            ▼              ▼
┌──────────────────────────────────────────┐
│ Mid/Long Term Rsh & Development (6.2, 6.3, etc) │ ·········▶
└──────────────────────────────────────────┘
            │              │
            ▼              ▼
┌────────────────────────────────────────────────────────────┐
│ {   Planning   } ─▶ Concurrent Engineering Office Operating Strategy │
└────────────────────────────────────────────────────────────┘
```

Air Force Manufacturing Technology Directorate

Concurrent Engineering

CRITERIA FOR CANDIDATE PROGRAMS

1. Application to AF weapon systems
   - High leverage program(s) with design issues to be resolved
   - High cost components with typically short life cycles
   - High cost components with complex production processes

2. Opportunity for innovative information exchange and use
   - Accommodate rapid trade offs among a variety of disciplines
   - Ability to solicit and then respond to end user inputs
   - Audit & verification trail that insures confidence

3. Not just a paper study
   - "Hands On" to validate concepts

4. Results extensible to subsequent programs

5. Leverages on-going AFWAL, Product Divisions, DoD, DARPA & Industry initiatives
   - Cost sharing sought

6. Compatible with existing and emerging Govt & Industry
   standards efforts

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Concurrent Engineering

TARGETS OF OPPORTUNITY

- Advanced Development Programs Aimed at Major Weapon Systems (6.3)

- Major Engineering Change on Weapon System Managed by Air Force Product Divisions (eg; Avionics Upgrade)

- Future Weapon Systems
    - Currently in Concept Stage (eg; ALS)

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Concurrent Engineering

Candidate Focused Initiatives

- Leverage AFWAL test facilities for concept demonstrations
    - Soilcit & merge concepts for concurrent engineering (MAGIC cockpit analogy)
    - MT's Integrated Test Facility aimed at supporting mfg Near term concepts – builds from ENE '88 & Cals EXPO
- Automated Avionics Design & Mfg
    - New Electronics Packaging Concepts — Support trade offs
    - Integrate Photonics, Wafer Scale Logic, VHSIC
    - Drive to lower costs, scheduled maintenance in electronics
- RAMCAD for AVIP
- Design for Assembly
    - Support decisions to resolve constraint issues among design, mfg, quailty, logistics support
    - Goal is to "design & build it right the first time" – dramatic ECO reduction

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Concurrent Engineering

Potential Partners

- Existing 6.3 effort-- "tag" on to existing work with addl' demo (TX?)
- ETL -- Bill Edwards
- MT Directorate (Fenter)
- AA -- Spector
- ML - Mel Ohmer, S. Leclair, et al
- DARPA
- AMRL/HRL
- CALS office -- R. Shorey Concurrent Engineering Thrust
- ASD/EN - Col Radford, et al
- Advanced Launch System SPO (AFSC/SD)

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Concurrent Engineering

How is success measured?

- Significant increase in the ability of technical specialists to interact and make trade offs before the design is "frozen".
- Reduction of engineering changes after the design is released
- Reduced maintenance costs through full application of R & M 2000 principles
- Ability to successfully manufacture and support the "as designed-as built" product in a much more efficient manner
- Improved responsiveness to the people in the field -- meets their real needs.

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Concurrent Engineering

EXAMPLES OF LONG TERM GOALS

- **Design Intent Capture**
- **Metrics for Info Transfer Across disciplines (levels of automation, etc)**
- **Design Synthesis**
- **Automated Tools**
    Tedious, non creative jobs
    Constraint Processing
- **Configuration Control**
    Weapon System
    Data about the Weapon System
    Meta Data
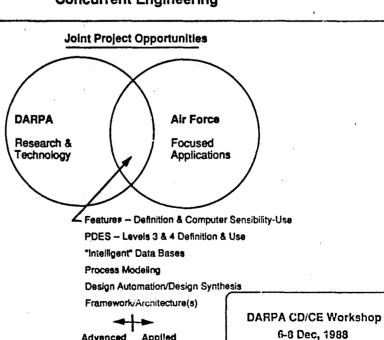
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Concurrent Engineering

Joint Project Opportunities

DARPA

Research &
Technology

Air Force

Focused
Applications

Features – Definition & Computer Sensibility-Use
PDES – Levels 3 & 4 Definition & Use
"Intelligent" Data Bases
Process Modeling
Design Automation/Design Synthesis
Framework/Architecture(s)

Advanced   Applied

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U.S. ARMY LHX PROGRAM

THE U.S. ARMY
&
CONCURRENT ENGINEERING

Mike Patterson
ASA (RDA)
(202) 695-8545

OBJECTIVES

- HIGHER QUALITY

- REDUCED COSTS

- REDUCED TIME TO FIELD

LHX DEM/VAL SOLICITATION

- 8 YEAR TIME HORIZON

- ATTACK HELICOPTER

- $7.5 M/COPY

- 7500 lbs.

- TWO CONTRACTOR TEAMS
  - BELL/McDONNELL DOUGLAS
  - BOEING/SIKORSKY

SOLICITATION CONSIDERATIONS

- DEFINITION?

- TQM vs. CONCURRENT ENGINEERING (CE)?

- PRODUCIBILTY vs. CE?

- LIABILITY (LEGAL & COST)?

- INCENTIVES TO INDUSTRY?

- GOVERNMENT "INHIBITORS"?

- SOURCE SELECTION METRICS?

METRICS CONSIDERATIONS

- PAST PERFORMANCE?

- PROFIT MARGINS?

- EVIDENCE OF PROCESSES?

- ABILITY TO SHOW "COST OF QUALITY"?

LHX SOLICITATION
TQM/Concurrent Design Plan

- PROPOSED "BEST MIX" OF APPROACHES, TOOLS & TECHNIQUES?

- COST, SCHEDULE & QUALITY IMPACTS?

- GOVERNMENT "INHIBITORS"?

- OFF-SETTING ACTIVITIES TO BE REPLACED INTEGRATED (THE "ILITIES")?

DESIRED RESULT

BEFORE: |——————————————————|

AFTER: |———————————|

COST?

SCHEDULE?

QUALITY?

SAE-APPROVED CE INITIATIVES
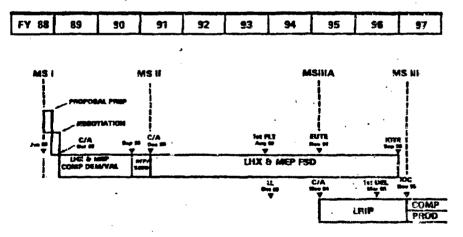
- START AN ANNUAL "BEST PRACTICES" COMPETITION IN DESIGN & ENGINEERING

- ESTABLISH AN ARMY ACQUISITION CENTER*
  - SHOWPLACE "BEST PRACTICES"
  - TEACH TQM & CE FUNDAMENTALS
  - EVALUATE "INHIBITORS"

- ESTABLISH AN ARMY MANUFACTURING BOARD

* STAFFED BY INDUSTRY & ACADEMIA

CONCURRENT DESIGN/CONCURRENT ENGINEERING

LIGHT HELICOPTER PROGRAM
(LHX)

6 DECEMBER 1988

LHX ▶ PROGRAM SCHEDULE

FY 88	89	90	91	92	93	94	95	96	97

MS I   MS II   MSIIIA   MS III

PROPOSAL PREP

NEGOTIATION

C/A   C/A   1st FLT   EUTE   KTTR

LHX & MEP COMP DEM/VAL |RFP   LHX & MEP FSD

1L   C/A   1st DEL   IOC

LRIP   COMP PROD

LHX CONTRACTOR TEAMS

FIRST TEAM

BOEING HELICOPTERS

SIKORSKY AIRCRAFT CO.

SUPERTEAM

BELL HELICOPTER
TEXTRON, INC.

MCDONNELL DOUGLAS
HELICOPTER CO

CONCURRENT ENGINEERING - TOTAL QUALITY MANAGEMENT

COMPLEMENTARY FUNCTIONS

CONCURRENT ENGINEERING

SYSTEMATIC APPROACH TO CREATING A PRODUCT DESIGN

TOTAL QUALITY MANAGEMENT

DISCIPLINED STRUCTURE TO CONTINUOUSLY IMPROVING
ALL PROCESSES

CONCURRENT ENGINEERING - TOTAL QUALITY MANAGEMENT

SIMILAR REQUIREMENTS

- FUNDAMENTAL SHIFT IN MANAGEMENT PHILOSOPHY

- TOP MANAGEMENT COMMITMENT/INVOLVEMENT

- TOTAL PROCESS ORIENTATION

- SYSTEMATIC APPROACH

- MULTI - FUNCTIONAL TEAMWORK INCLUDING CUSTOMER

LHX CONCURRENT ENGINEERING

- INTEGRAL PART OF DEM/VAL

- MULTIFUNCTIONAL

  - ENGINEERING   - MATERIEL   - MARKETING
  - SUPPORTABILITY   - PRODUCIBILITY   - MFG. ENGINEERING
  - OPERATIONS   - FINANCE
  - PRODUCT INTEGRITY

- PRIMARY OBJECTIVES

  - TRANSLATE CUSTOMER EXPECTATIONS INTO REQUIREMENTS
  - FOSTER CONTINUOUS IMPROVEMENT THROUGH TEAM WORK
  - INTEGRATE DESIGN TO MANUFACTURING & SUPPORT PROCESSES

CONCURRENT DESIGN/ENGINEERING

MULTIFUNCTIONAL ←——→ INTERDISCIPLINARY

STRUCTURES
ROTORS
FUEL
DRIVE
ARMAMENT
MEP

PRODUCIBILITY
ENGINEERING
RAM
TRAINING
COST
LOGISTICS

LHX NATURAL WORK GROUPS

MANPRINT/
HUMAN FACTORS   DESIGN TO COST/L.C.C.   SUBCONTRACTORS

LOGISTICS   TRAINING

R&M

HEALTH
HAZARDS

ENGINEERING
DESIGN

PRODUCIBILITY
• MANUFACTURING ENGINEERING
• TOOLING
• QUALITY ENGINEERING

SYSTEM SAFETY

CO-LOCATED WITH DESIGN FUNCTIONS

LHX CD/CE PLAN

- OPERATIONAL PROCEDURES
- MANAGEMENT DISCIPLINE AND PROCEDURES
- IMPLEMENTATION OF CAD/CAE
- MIX – OF – TOOLS
- ESTIMATED COST AND SCHEDULE
- INHIBITORS
- IDENTIFICATION OF OFFSETTING ACTIVITIES

SUMMARY

QUANTIFIABLE DIFFERENCES BETWEEN CD/CE
AND TYPICAL DESIGN PROCESSES

DARPA-DMO PROGRAMS

DICE (DARPA INITIATIVE IN CONCURRENT ENGINEERING)

GE/UWVA

DICE: DARPA's Initiative in Concurrent Engineering

Research Issues in

System Architectures for Concurrent Engineering

presented by
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lewisjw@ge-crd.arpa

General Electric Company
Corporate Research and Development
PO Box 8, Schenectady, NY 12301

Other members of the DICE architecture team who contributed to but do not necessarily agree with these remarks include: RT Wood, manager IAT, JW Erkes, manager IAM, J. Czechowski, B. Sarachon, F. Stocker and W. Uejio from GE Corporate Research as well as RA Reddy, director CERC, J. Cleetus, J. Kannan and F. Lonvano from West Virginia University; S. Finger, M.S. Fox, Carnegie Mellon University; and M. Wozny, M. Hardwick, Rensselaer Polytechnic Institute.

DICE Architecture: Objectives

Preliminary design   Costing, Life Cycle   Aerodynamics Mechanical Design

Central Services   Materials   Drafting Process Design

- *User view:* Enabling the design engineer to identify and exploit the distributed human and computer resources of the enterprise as if they were local.
- *Developer view:* Providing a convenient framework within which a variety of system, modeling, user interface, and applications tools can share common models.
- *Maintainer view:* Integrating tools more easily, responding more quickly to the engineer's requirements, and building more extensive models
- *Enterprise view:* Coordinating the activities of the various groups and improving both human and computer communications.

Overall: 2:1 Reduction in design cycle time

A Model Concurrent Engineering Problem:
Turbine Blade Design

Aircraft   Aircraft Engine   Turbine Blade

Interacting Disciplines

- Aerodynamics
- Mechanical design
- Materials
  Thermal
  Process design
  Drafting
  Quality
  Costing
  . . .

Performance Criteria

- Efficiency
- Weight
- Vibration
- Stress
  Foreign object damage
  Cost, yield
  Life
  Logistics
  . . .
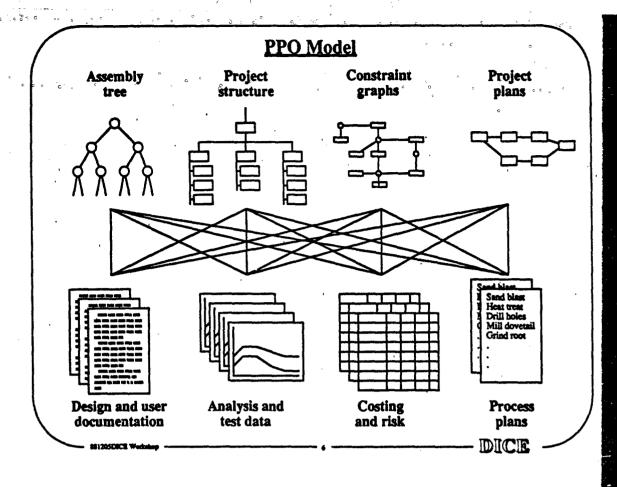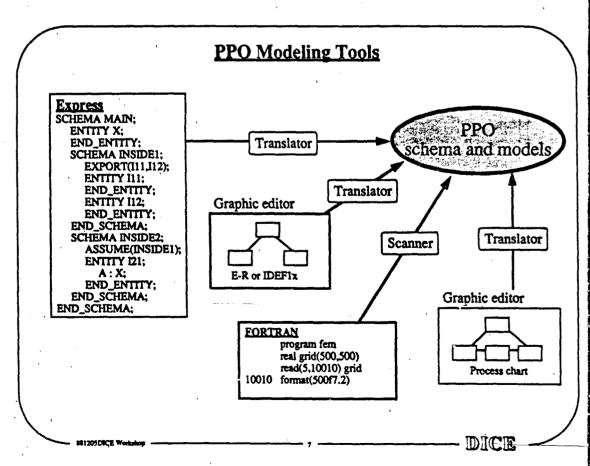
881205DICE Workshop —————— 3 —————— DICE

Concurrency: Some Definitions

Happening at the same time   2. Operating in conjunction

engr ▬▬▬▬▬▬▬▬▬   ▬▬▬▬▬▬▬▬▬

mfgr ▬▬▬▬▬▬▬▬▬   ▬▬▬▬▬▬▬

a. **Phase:** concurrency among conceptual design, preliminary design, detail design, process design, cost, manufacturing, and quality;

b. **Design:** concurrent pursuit of multiple design alternatives;

c. **Discipline:** concurrency among aerodynamics, structures, stress, thermal, process engineering and other engineering disciplines;

d. **RDT:** concurrent pursuit of research, development, and tools;

e. **Methodology:** concurrency among requirements specification, high level design, detail design, implementation, integration, test, and maintenance activities; and

f. **Execution:** concurrency among different groups and programs sharing data and processors.

881205DICE Workshop —————— 4 —————— DICE

PPO Model

Assembly tree

Project structure

Constraint graphs

Project plans

Design and user documentation

Analysis and test data

Costing and risk

Process plans

Sand blast
- Sand blast
- Heat treat
- Drill holes
- Mill dovetail
- Grind root

PPO Modeling Tools

Express
```
SCHEMA MAIN;
    ENTITY X;
    END_ENTITY;
    SCHEMA INSIDE1;
        EXPORT(I11,I12);
        ENTITY I11;
        END_ENTITY;
        ENTITY I12;
        END_ENTITY;
    END_SCHEMA;
    SCHEMA INSIDE2;
        ASSUME(INSIDE1);
        ENTITY I21;
        A : X;
        END_ENTITY;
    END_SCHEMA;
END_SCHEMA;
```

Translator → **PPO schema and models**

Translator

Graphic editor

E-R or IDEF1x

Scanner

Translator

FORTRAN
```
        program fem
        real grid(500,500)
        read(5,10010) grid
10010   format(500f7.2)
```

Graphic editor

Process chart

Data Base

What
- In memory: high speed, but persistence and sharing are problems (CROSE)
- On disk: persistent, shareable, and language independent; but generally slower (IRIS)

How
- Hierarchical
- CODASYL
- Relational (SQL)
- Object-oriented
- Frames
- Logic
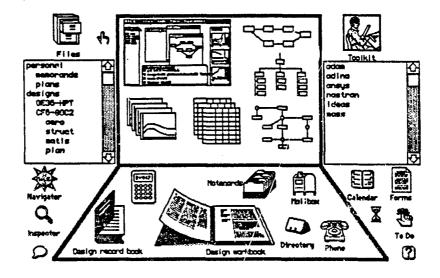
Views
- Simultaneous relational and object oriented
- Multiple user profiles and access permissions

Language Issues
Ideal: totally transparent to host language, accessible to all languages, runs at memory speeds, persistent as required, shareable as required, loads quickly, schema can be changed without recompilation, old/new schema can coexist, dynamic objects, and little storage/access time overhead over equivalent simple record.
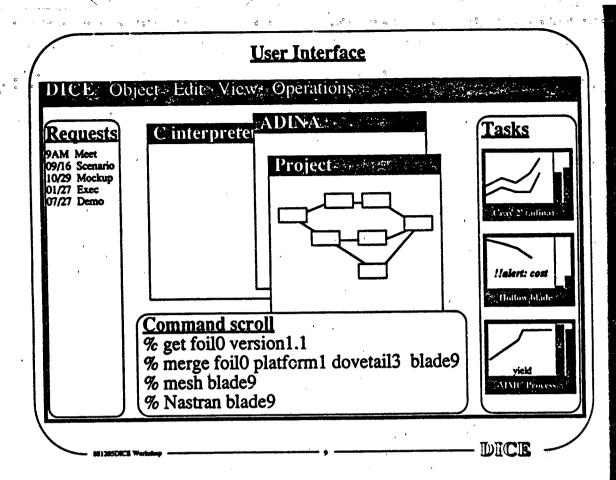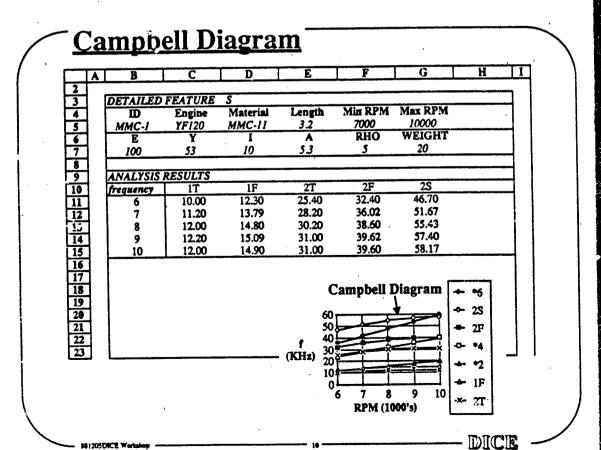
THEO: THe Engineer's Office

A collection of design-oriented user-interface idioms

User Interface

DICE Object Edit View Operations

Requests

9AM Meet
09/16 Scenario
10/29 Mockup
01/27 Exec
07/27 Demo

C interpreter

ADINA

Project

Tasks

Gray 2° radial

!!alert: cost

Hollow blade

yield

MMC Process

Command scroll
% get foil0 version1.1
% merge foil0 platform1 dovetail3 blade9
% mesh blade9
% Nastran blade9

Campbell Diagram

	A	B	C	D	E	F	G	H	I
2									
3		DETAILED FEATURE	S						
4		ID	Engine	Material	Length	Min RPM	Max RPM		
5		MMC-1	YF120	MMC-11	3.2	7000	10000		
6		E	Y	I	A	RHO	WEIGHT		
7		100	53	10	5.3	5	20		
8									
9		ANALYSIS RESULTS							
10		frequency	1T	1F	2T	2F	2S		
11		6	10.00	12.30	25.40	32.40	46.70		
12		7	11.20	13.79	28.20	36.02	51.67		
13		8	12.00	14.80	30.20	38.60	55.43		
14		9	12.20	15.09	31.00	39.62	57.40		
15		10	12.00	14.90	31.00	39.60	58.17		
16									
17									
18									
19									
20									
21									
22									
23									

Campbell Diagram

f (KHz)

RPM (1000's)

Legend: *6, 2S, 2F, *4, *2, 1F, 2T

Frequency Analysis

	A	B	C	D	E	F	G	H	I
2									
3		SELECT DESIGN FO R ANALYSIS							
4		ID	Date	Material	Length	Min RPM	Max RPM		
5		Typical steel	1-May-67	FE	1.5	6000	9200		
6		Typical Ti	3-Mar-70	TI	2.3	7000	10000		
7		MMC-1	31-May-80	MMC-11	3.2	7000	10000		
8		MMC-2	25-Jun-82	MMC-23	3.3	7000	10000		
9		MMC-3	30-Jul-83	MMC-33	3.2	7000	10000		
10									
11		DETAILED FEATURE S							
12		ID	Engine	Material	Length	Min RPM	Max RPM		
13		MMC-1	YF120	MMC-11	3.2	7000	10000		
14		E	Y	I	A	RHO	WEIGHT		
15		100	53	10	53	5	20		
16									
17		SELECT MODES							
18		*2							
19		*4							
20		*8							
21									
22									
23									
24									
25									

Planning for Concurrent Engineering

Cooperative Work

Groups
aero
mech
matls

Groups
aero

mech

matls

Concurrent design requires far more interaction than is typical of current sequential methodologies.

Unified Architecture Summary

1. Problems
- Multiple models and data bases
- Simple info models, limited scope
- Incompatible tools and data bases
- Task management and communication
- Information transfer
- Incomplete optimization (e.g., life cycle)
- Resource identification/planning
- Limited access to information

2. A Design for the Architecture
- Unified master data dictionary
- PDES/Express, CASE tools
- Wrappers and feature linking
- Generalized task control and mail interface
- Data base-driven file translators
- Constraint graphs and embedded planners
- Information manager
- Integrated backbone language and data base

3. A Development Plan
- Tool, invention, and research foci
- Progressive refinement: fast transition from research to practice
- Phases: Paper mockup, executable mockup, demonstration, prototype, ...

Major Modules
- DICE for DICE (CERC)
- Design fusion workstation modules (CMU)
- MINI-DICE (WVU)
- Electronics assembly module (Cimflex)
- Unified architecture and mechanical problem (CR&D, WVU, RPI, NCSU)

Objective: 2-1 cycle time reduction

DICE ARCHITECTURE

RAMANA REDDY

CONCURRENT ENGINEERING RESEARCH CENTER

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EXECUTIVE COMMITTEE

RAMANA REDDY	---------	WVU/CERC
JOSEPH ERKES	---------	GE/CRD
RALPH WOOD	---------	GE/CRD
MARK FOX	---------	CMU/RI

DICE VISION

Develop an engineering environment that is:

- Distributed
- Heterogeneous
- Near-paperless
- Concurrent

To promote

--> Cooperative   design

And reduce

--> Concept-to-product   cycle   time

11/30/88 ——————————————— WVU/CERC

DICE ASSUMPTIONS

- Heterogeneous spatially distributed computing environment

- Utilization of existing tools

- Enforcement of authorization and security protocols

- Smooth evolution from existing culture

- Fail-soft and unobtrusive environment

- Co-existence with evolving standards

11/30/88 ——————————————— WVU/CERC
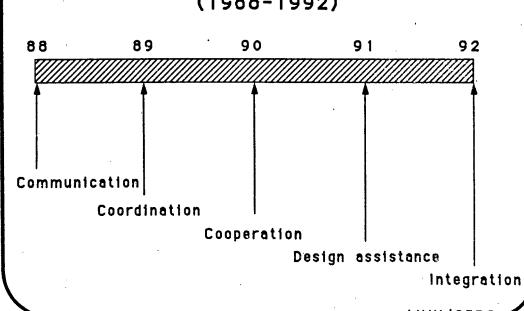
DESIGN TRANSACTIONS
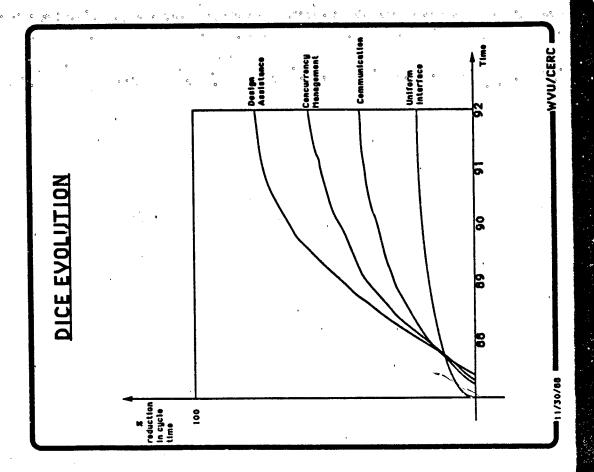
- Multi-media communication (Phone, Fax, E-mail...)

- Activity planning and coordination (Project Lead)

- Negotiation with high bandwidth communication (meetings)

- Local analyses

- Sign-off and authorization

- Progressive decision making

- Access to databases, compute servers and remote tools

- Archival of designs

- Document Preparation and access management

11/30/88 ———————————————————— WVU/CERC

DICE EVOLUTION

(1988-1992)

88   89   90   91   92

Communication

Coordination

Cooperation

Design assistance

Integration

11/30/88 ———————————————————— WVU/CERC

DICE EVOLUTION

Graph axes: "% reduction in cycle time" (vertical, 100), "Time" (horizontal, 88 89 90 91 92). Curves labeled: Design Assistance, Concurrency Management, Communication, Uniform Interface.

11/30/88 — WVU/CERC
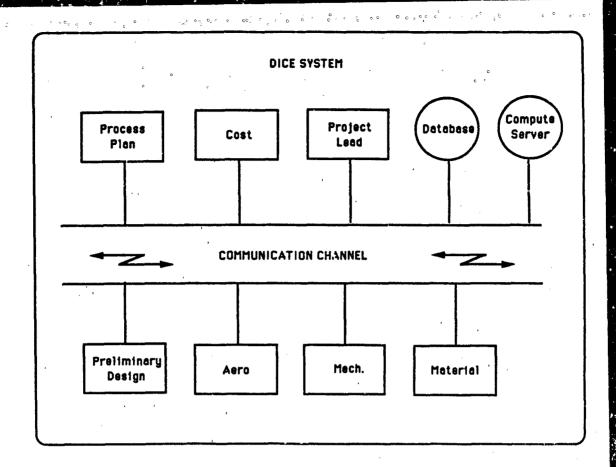
DICE EVOLUTION

- Transparent communication

- Coordination and cooperation

- Concurrent execution of transactions

- Negotiation and concurrent management

- Task planning

- Constraint management

- Design assistance

11/30/88 — WVU/CERC

DICE SYSTEM

```
┌──────────┐   ┌──────────┐   ┌──────────┐     ╭─────────╮     ╭─────────╮
│ Process  │   │   Cost   │   │ Project  │    │ Database │    │ Compute │
│   Plan   │   │          │   │   Lead   │    │          │    │  Server │
└────┬─────┘   └────┬─────┘   └────┬─────┘     ╰────┬────╯     ╰────┬────╯
     │              │              │               │               │
─────┴──────────────┴──────────────┴───────────────┴───────────────┴─────
         ←↯→         COMMUNICATION CHANNEL          ←↯→
─────┬──────────────┬──────────────┬───────────────┬─────────────────────
     │              │              │               │
┌────┴─────┐   ┌────┴─────┐   ┌────┴─────┐     ┌────┴─────┐
│Preliminary│  │   Aero   │   │  Mech.   │     │ Material │
│  Design  │   │          │   │          │     │          │
└──────────┘   └──────────┘   └──────────┘     └──────────┘
```
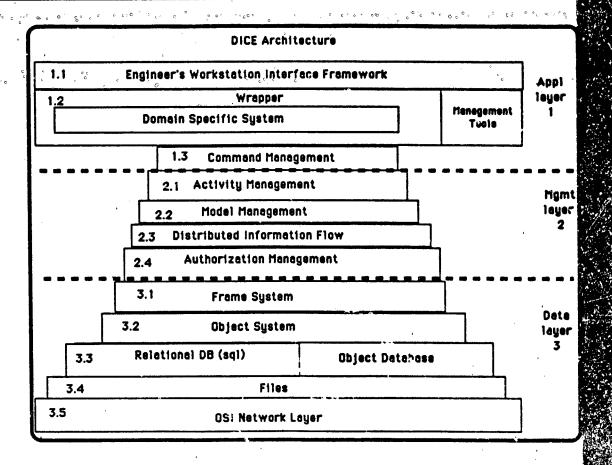
DICE SYSTEM LAYERS

1. Application layer

2. Management layer

3. Data layer

DICE Architecture

1.1 Engineer's Workstation Interface Framework			**Appl layer 1**
1.2 Wrapper		Management Tools	
Domain Specific System			

1.3 Command Management

2.1 Activity Management

2.2 Model Management

2.3 Distributed Information Flow

2.4 Authorization Management

Mgmt layer 2

3.1 Frame System

3.2 Object System

3.3 Relational DB (sql) — **Object Database**

3.4 Files

3.5 OSI Network Layer

Data layer 3
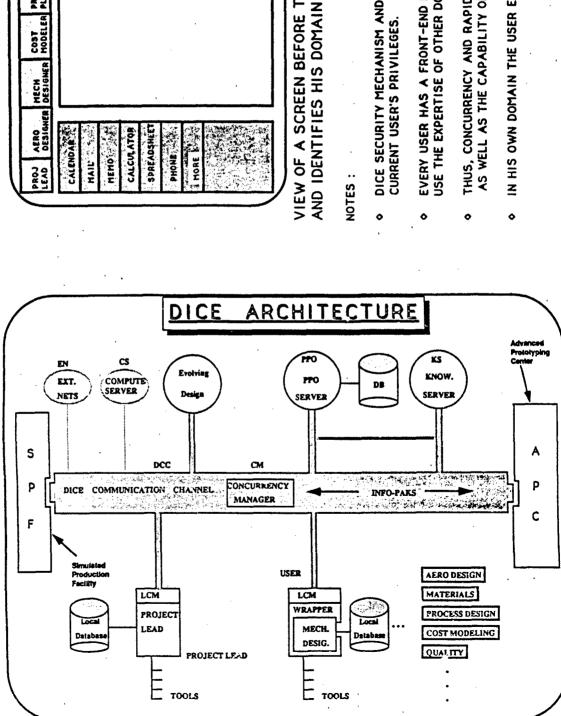
DICE SYSTEM COMPONENTS

1. The UIMS system

2. DICE Communication Channel (DCC)

3. Concurrency Manager (CM)

4. PPO server -- Product, Process, Organization

5. Dice Blackboard (DBB)

6. DICE object management system

7. Compute Server

8. External networks
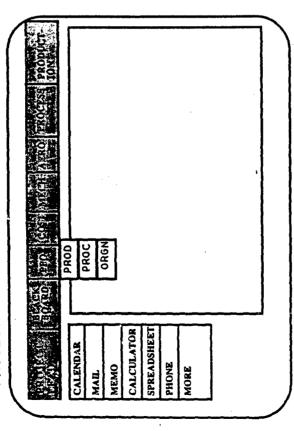
9. Knowledge Server

VIEW OF A SCREEN BEFORE THE USER SIGNS ON
AND IDENTIFIES HIS DOMAIN NEED.

NOTES :

◇ DICE SECURITY MECHANISM AND USER SIGN-ON ENABLE THE
CURRENT USER'S PRIVILEGES.

◇ EVERY USER HAS A FRONT-END MENU THAT ALLOWS HIM TO
USE THE EXPERTISE OF OTHER DOMAINS, WITHIN LIMITS.

◇ THUS, CONCURRENCY AND RAPID ACCESS ARE IMPROVED,
AS WELL AS THE CAPABILITY OF EVERY USER.

◇ IN HIS OWN DOMAIN THE USER ENJOYS THE HIGHEST PRIVILEGE.

Screen menu — top bar: SIGN ON | MATERIALS | PRODUCTION SIMULATOR | PROCESS PLANNER | COST MODELER | MECH DESIGNER | AERO DESIGNER | PROJ LEAD

Screen menu — bottom bar: CALENDAR | MAIL | MEMO | CALCULATOR | SPREADSHEET | PHONE | 1 MORE

DICE ARCHITECTURE

EN — EXT. NETS
CS — COMPUTE SERVER
Evolving Design
PPO — PPO SERVER
DB
KS — KNOW. SERVER
Advanced Prototyping Center

SPF — Simulated Production Facility
DCC
CM
DICE COMMUNICATION CHANNEL
CONCURRENCY MANAGER
INFO-PAKS
APC

LCM — PROJECT LEAD
Local Database
PROJECT LEAD
TOOLS

USER
LCM — WRAPPER — MECH. DESIG.
Local Database
TOOLS

AERO DESIGN
MATERIALS
PROCESS DESIGN
COST MODELING
QUALITY

PROJECT LEAD'S SELECTION OF P-P-O MENU

PRODUCT	PROCESS	ORGANIZATION
PARTS_LIST		
ONE-LEVEL EXPLOSION		
GEOMETRY		
INVENTORY		
MATERIAL_SPECS		

PART NO : ZA 17895
DESCRIPTION : BLADE

COMPONENTS	DESCRIPTION	QUANTITY
AB 56347	SHANK	1
WS 78945	DOVETAIL	1
AQ 23978	PLATFORM	1

◊ THE PL HAS SELECTED THE _PRODUCT_ MENU'S _PARTS_LIST_ OPTION AND SPECIFIED PART NO _ZA 17895_.

◊ HE CAN LIKEWISE EXAMINE OTHER FACETS OF THE _PART_ MENU, OR GO TO THE _PROCESS_ OR _ORGANIZATION_ MENU.

◊ THE PL'S CAPABILITY OF ACCESS TO THE P-P-O, THOUGH EXTENSIVE, DOES NOT ENCOMPASS ALL THAT A DATA BASE _ADMINISTRATOR_ MAY DO WITH THE P-P-O.

◊ FOR EXAMPLE, THE P-P-O IS NOT MODIFIED BY THE PROJECT LEAD DIRECTLY. ONLY THE EVOLUTION OF THE NEW DESIGN WITH THE ASSENT OF OTHER DESIGNERS CAN RESULT IN A PPO CHANGE.

PROJECT LEAD'S VIEW :

PROD
PROC
ORGN

CALENDAR
MAIL
MEMO
CALCULATOR
SPREADSHEET
PHONE
MORE

◊ THE PROJECT LEAD HAS A COMPLETE MENU OF CAPABILITIES WHICH HE WILL USE TO GAIN INSIGHT INTO THE EVOLVING DESIGN.

◊ HERE HE PULLS DOWN THE P-P-O MENU AND CAN VIEW HIS OPTIONS.

◊ _PRODUCT:_ INFORMATION ON A PART.
  PROCESS: INFORMATION ON THE PROCESS FOR A PART.
  ORGANIZATION: INFORMATION ON PRODUCTION ACTIVITIES.

1. Aero has completed his "best" blade shape for the preliminary design specification and put it on the blackboard.

2. Project Lead decides to do a rough-cut analysis of this blade shape for stress and thermal. He uses a coarse mesh for FEA and a uniform temperature for the blade. He issues the command "$DO_COARSE_PD" to the interface wrapper.

3. This command is transmitted to the LCM which registers the command and looks up its tables and issues in turn 2 parallel commands to remote processes.

4. These commands are queued on the outgoing messages queue.

5. The DCC reads from the queue and transmits the 2 messages to the 2 destination workstations.
   a. Compute Server
   b. Thermal Analysis Workstation

6. When the message 5(a) reaches the compute server, it is first queued into the input queue by the LCM.

7. The LCM then looks for a named process in the compute server to satisfy the request. There are 3 cases:
   i. The process is running but is busy
   ii. The process is ready but idling
   iii. The process is not started
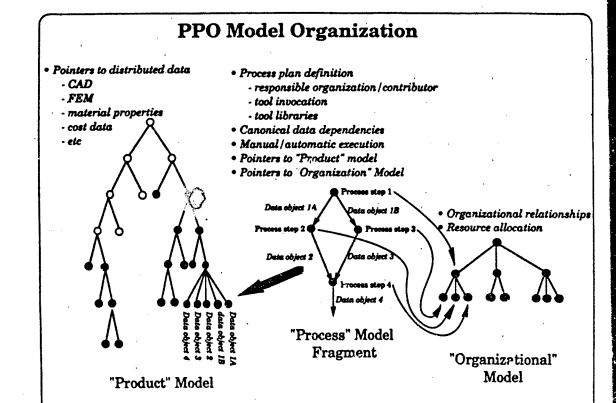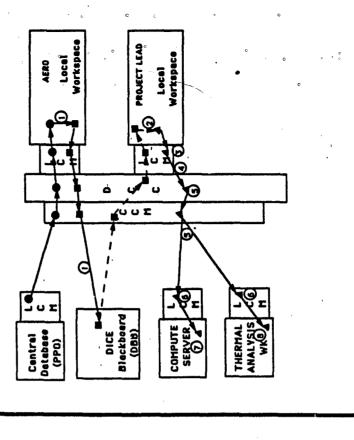
Action:
   i. Put message for input queue into the queue for the process named
   ii. Hand over the message in memory to the ready process
   iii. Load the process and hand over the message to it

8. Message 5(b) is handled like message 5(a) at the Thermal Analysis workstation.

9. When the two services (requested by 5(a) and 5(b) complete successfully, each process will return the results to the PL's workstation, with the id of the original message embedded.

PPO Model Organization

- **Pointers to distributed data**
  - CAD
  - FEM
  - material properties
  - cost data
  - etc

- **Process plan definition**
  - responsible organization/contributor
  - tool invocation
  - tool libraries
- **Canonical data dependencies**
- **Manual/automatic execution**
- **Pointers to "Product" model**
- **Pointers to "Organization" Model**

- **Organizational relationships**
- **Resource allocation**

Process step 1
Data object 1A
Data object 1B
Process step 2
Process step 3
Data object 2
Data object 3
Process step 4
Data object 4

Data object 1A
data object 1B
Data object 2
Data object 3
Data object 4

"Process" Model Fragment

"Product" Model

"Organizational" Model

DICE

CONCURRENCY MANAGER SCENARIO

AERO
Local
Workspace

PROJECT LEAD
Local
Workspace

L C M

Central
Database
(PPO)

DICE
Blackboard
(DBB)

COMPUTE
SERVER

THERMAL
ANALYSIS
WK(8)

10. In the PL workstation when the reply to message 5(a) is received it logs the result on disk and performs synchronization. It finds that the reply to message 5(b) has not been received yet, therefore does not perform further tasks.

11. When reply to message 5(b) is also received it logs it on disk, and checks the task synchronization algorithm again. This time it finds yes, it can now start task 3 to compute the parameters for the next iteration in FEA and TEMA (thermal analysis). Task 3 is done in the PL's workstation.

12. Task 3 is activated by dispatching it in the PL workstation as at 7 above.

SPECS OF CM VERSION 1

○ **WORKSTATION TASK PERFORMANCE CAPABILITY CAPTURE**

Each workstation or server has the capability to perform a category of tasks with procedures available to it. What these capabilities are and the data they require are described in a catalog of procedures for each node.

○ **PARALLEL DISTRIBUTED COMMAND LANGUAGE DEFINITION**

To define the distributed execution of a job as the net result of multiple procedures executed on different nodes of the network, requires a specification language. The language will be able to define how a macro job is split into a network of many tasks done remotely in a distributed fashion, and will also specify the necessary precedence chain implied by the network.

○ **INTERPRETATION OF COMMAND LANGUAGE**

Having defined the splitting of a job into procedures, there will be at run-time an interpreter which sends messages to start up remote tasks, or loads and starts up local tasks, so that the job may be done as a set of steps.

○ **TASK SPLITTING AND CATALOGING**

The entire set of task capabilities of all the nodes of the network will be described by an administrator, and they will be cataloged and made known to the entire network. The short-hand commands to invoke a complex job will be cataloged as names, with their necessary options and data file specifications.

○ **TASK LOGGING**

All tasks which are scheduled for performance will be logged first. Task management and reporting in a later phase will require this.

○ **TASK AUTHORIZATION**

Tasks require authorization since they will use resources, modify the data base, and access remote computers. As part of the user profile capture, there will be information added by an administrator to signify the execute permissions a user has at various nodes.

CONCURRENCY MANAGER SCENARIO

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◇ **TASK SYNCHRONIZATION**

When tasks are completed and returned to the originating node the command language interpreter must perform task synchronization according to the necessary precedence defined for the job. Results are held, and tasks are started up only upon availability of successful task completion results of logically precedent tasks.

◇ **IN/OUT MESSAGE QUEUING**

Messages which are to be sent to other nodes, and those received from other nodes are kept in a queue. It is from these queues that tasks are dispatched, according to their priority and requirement of resources. It is assumed that if the relevant server task is running then the message just has to be copied from the in/out queue to the queue of that server task. Otherwise the task must be dispatched, i.e., actually loaded and the message request handed to it.

◇ **INTERFACES TO APPLICATIONS**

There are two interfaces to applications. The first is when applications wish to send a message (command) requesting service to another node. The second is when a message has arrived at a server node and the application must pick up the requesting message to perform the required service. In both cases the concurrency manager intervenes and mediates the communication.

◇ **LOCAL AND REMOTE TASK DISPATCHING**

The remote tasks must be scheduled and dispatched and this is why there is a local concurrency manager (LCM) in every workstation to handle the analysis of incoming messages to know which task has to be fired up to handle a message requesting a specific service. The LCM has tables which tell it what procedures are available locally, and which are available remotely, and what is the status of local tasks (running and idle, running and busy, not loaded). It also knows what queues are designated for stacking messages for each distinct task. Operating system calls will be used by the concurrency manager to load programs, or to issue calls to place a message in an OS "mailbox" on which an idling server will wait.

Transactions description

1. A design agent requests a copy of a framgent of the PPO.

- The command is issued through the interface wrapper.

- The command is transmitted to the LCM which registers the commands and issues the command to the PPO server.

- The command is queued on the outgoing message queue.

- The DCC reads from the queue and transmits the message to the PPO server.

- When the message reaches the PPO server, it is queued into the input queue by the LCM.

2. The PPO server satisfies the request returning the results to the design agent workstation. The returning message has the id of the original message embedded.

- When the message is received in the design agent's workstation, it is logged on disk.

3. The design agent prepares some assertions related to that copy of the PPO fragment. The assertions are prepared by a design agent based on its view of the design process. The assertions are based on intended transformations to the PPO fragment. The assertion originates from a local interaction process. A design agent works using its private local workspace.

4. The design agent publishes the final set of assertion in the DICE blackboard.
The flow of assertions from a design agent to the blackboard is handled with the assistance of the concurrency manager using the DCC. The general process is the same as described in 1 above. More details about the flow of assertions in the DICE architecture are discussed in the documentation related to the DICE communication channel, the concurrency manager and the info-pak.

DICE BLACKBOARD TRANSACTIONS

Central Database (PPO)

DA Local workspace

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5. The DBB broadcasts assertions to other parties in the DICE architecture.

The assertions going out from the DBB may take different forms. In general those assertions are the result of transformations applied to the assertions that arrive to the DBB. Assertions arriving to the DBB originate activities withing the blackboard. Assertions arriving to the blackboard may originate the creation of new assertions, the activation of certain tasks, the transformation of the original assertions etc. The blackboard is an active entity that drives part of the activities as related to the design process.

A dialog process is established through the blackboard. Assertions are interchanged as related to the current focus of activities.

6. Each of the design agents involved in the current focus of the blackboard activities performs local transformations to the transactions that have been broadcasted to him from the blackboard.
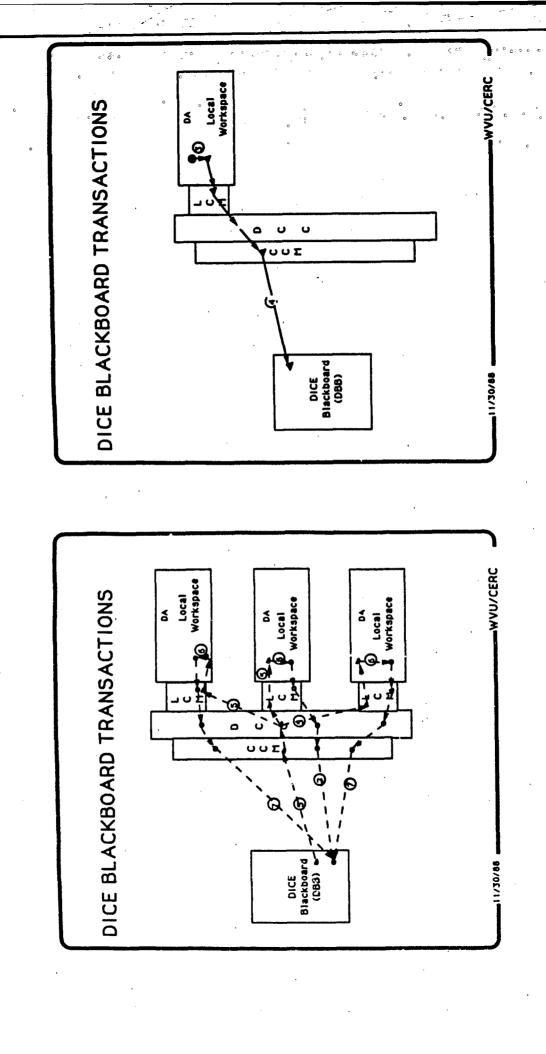
7. New transactions are sent to the blackboard from each of the involved desgin agents.

This is a cyclic activity. Before a set of assertions arrive into the blackboard there is certain status of stability. The arriving of a new set of assertions originates some inestability that activates new flow of assertions among the design agents through the blackboard. Assertions flow until a new status of stability is reached when there is an agreement on the transformed status of the blackboard.

8. The final results from previous interaction are incorporated in the PPO by the project lead.

DICE BLACKBOARD TRANSACTIONS

DICE BLACKBOARD TRANSACTIONS

DICE BLACKBOARD TRANSACTIONS

Central Database (PPO)

PROJECT LEAD

Local Workspace

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SPECS OF DBB VERSION 1

○ **REPRESENTATION**

The ability to represent the mutual dependency of designers, constraints pertaining to the design, and certain heuristics employed by a lead designer, is a basic feature of the blackboard. Besides, it has the ability to hold parametric values of assertions (see below) and pointers to the parts of the design currently in focus for the co-operating designers to work on.

○ **FOCUS**

This comprises one or more concurrently worked on parts of the design, held in focus and made visible to all the designers. The lead designer's guiding vision as to how the design work should be attacked in parallel by the different groups, is what is held in focus.

○ **ASSERTION**

Designers working on a part of the design with the special tools of their domains, will analyze, iterate, optimize, and arrive at the "best" values or shapes for the current focus of the blackboard. These are then formally asserted on the blackboard and made visible to the community of co-operating designers.

○ **DEPENDENCY**

Not all assertions by others affect a designer. But those that do have consequences for his domain of work must be notified automatically. And it must be known to the blackboard who has the highest authority on a particular part of the design. These are stored in tables, and could well be part of what is called the product-process-organization (PPO) model.

○ **SIGN-OFF**

There should be a formal process of sign-off by which the person authorized to accept the assertions takes responsibility. The lead designer can cause them to be reviewed before acceptance. But the idea is that the common visibility afforded by the blackboard and its mechanism of automatic notification, ensures that everybody who has a say in that part of the design, does get to evaluate its acceptability from the relevant angles.

0 **INITIALIZATION FROM PPO OR PROJECT LEAD'S WORKSTATION**

To start up the design evolution an agent must place on the blackboard what is the current focus and the pointers to the data for the starting version of the design. This can be an earlier design, in which case it is pulled to the blackboard (not the contents but the pointers to it and the major features) from the PPO data base. Or it can be the result of the preliminary design process undertaken by the lead designer.

0 **USER INTERFACES TO BB ON OTHER WORKSTATIONS**

Any designer can view the current status of the design evolution by looking at the blackboard. The various parts of it will be made visible, and his need for interaction with the blackboard for his own work will be catered to by a specifice interface for the designer to the blackboard.

DICE ON DICE

Early prototypes of DICE system will be used to manage DICE system development.

- Remote browsing/editing of documents

- Communications

- Information distribution

- Version management

- Automated integration (Super-MAKE)

- Project management

EXPERT SYSTEMS FOR MANUFACTURING OF SMART WEAPONS

COMPONENTS

CSDL

DARPA PROGRAM: EXPERT SYSTEMS FOR MANUFACTURE OF SMART WEAPONS COMPONENTS

- DEVELOP A CONCURRENT BASELINE ANALYSIS OF AN AIRBORNE MISSILE SYSTEM COMPONENT DESIGN AND MANUFACTURING SYSTEM.

  FOCUS: SEEKER HEAD OR GUIDANCE PACKAGE

- PERFORM A COMPREHENSIVE INVESTIGATION OF PRESENT AND PROPOSED KNOWLEDGE-BASED PROGRAMS TO DETERMINE SUITABILITY OR POTENTIAL AS BASIS FOR SYSTEMS FOR THE CLASS OF PRODUCTS & PROCESSES SELECTED.

- DEVELOP SEVERAL OF THE MOST PROMISING PROGRAMS TO A POINT WHERE THEY MAY BE INTEGRATED WITH PRESENT CONCURRENT DESIGN TECHNIQUES.

- WITHIN THE TIME AND FISCAL CONSTRAINTS TEST THE INTEGRATED PROGRAMS (CONCURRENT DESIGN TECHNIQUES AND KB TECHNIQUES) AGAINST THE ANALYSIS PERFORMED EARLIER.

TASK 1

CONCURRENT BASELINE ANALYSIS

    PHASE 1A

    PHASE 1B

TASK 2
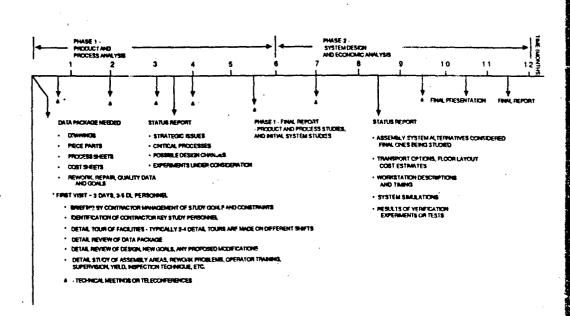
INVESTIGATE PRESENT AND
PROPOSED KB PROGRAMS

TASK 3

DEVELOP NEW KB PROGRAMS
IMPLEMENT TEST PLATFORM

Δ   Δ
SPEC   DELIVERY

TASK 4

TEST NEW TOOLS - INTEGRATED
CONCURRENT DESIGN TECHNIQUES
AND KB TECHNIQUES

Time axis: 2 4 6 8 10 12 14 16 18 20 22 24

PHASE 1 - PRODUCT AND PROCESS ANALYSIS

PHASE 2 - SYSTEM DESIGN AND ECONOMIC ANALYSIS

TIME (MONTHS)

1 2 3 4 5 6 7 8 9 10 11 12

FINAL PRESENTATION   FINAL REPORT

DATA PACKAGE NEEDED

- DRAWINGS
- PIECE PARTS
- PROCESS SHEETS
- COST SHEETS
- REWORK, REPAIR, QUALITY DATA AND GOALS

* FIRST VISIT - 3 DAYS, 3-5 DL PERSONNEL

- BRIEFING BY CONTRACTOR MANAGEMENT OF STUDY GOALS AND CONSTRAINTS
- IDENTIFICATION OF CONTRACTOR KEY STUDY PERSONNEL
- DETAIL TOUR OF FACILITIES - TYPICALLY 2-4 DETAIL TOURS ARE MADE ON DIFFERENT SHIFTS
- DETAIL REVIEW OF DATA PACKAGE
- DETAIL REVIEW OF DESIGN, NEW GOALS, ANY PROPOSED MODIFICATIONS
- DETAIL STUDY OF ASSEMBLY AREAS, REWORK PROBLEMS, OPERATOR TRAINING, SUPERVISION, YIELD, INSPECTION TECHNIQUE, ETC.

Δ - TECHNICAL MEETINGS OR TELECONFERENCES

STATUS REPORT

- STRATEGIC ISSUES
- CRITICAL PROCESSES
- POSSIBLE DESIGN CHANGES
- EXPERIMENTS UNDER CONSIDERATION

PHASE 1 - FINAL REPORT
- PRODUCT AND PROCESS STUDIES, AND INITIAL SYSTEM STUDIES

STATUS REPORT

- ASSEMBLY SYSTEM ALTERNATIVES CONSIDERED FINAL ONES BEING STUDIED
- TRANSPORT OPTIONS, FLOOR LAYOUT COST ESTIMATES
- WORKSTATION DESCRIPTIONS AND TIMING
- SYSTEM SIMULATIONS
- RESULTS OF VERIFICATION EXPERIMENTS OR TESTS

FIGURE 1. SCHEDULE FOR TASK 1

DELIVERABLES

- DETAIL CONCURRENT DESIGN ANALYSIS

    NOTE: TWO MISSILE COMPONENTS HAVE BEEN SELECTED FOR DETAIL ANALYSIS

- IDENTIFICATION OF KNOWLEDGE-BASED TOOLS NEEDED TO SUPPORT THE ANALYSIS, DESIGN AND IMPLEMENTATION OF ADVANCED MANUFACTURING SYSTEMS FOR DOD (END OF 1ST YEAR)

- IDENTIFICATION OF FURTHER RESEARCH NEEDED TO EXPAND THE PRESENT SET OF CONCURRENT DESIGN TOOLS AND TECHNIQUES, AND KNOWLEDGE-BASED SYSTEMS (END OF 1ST YEAR)

- ANALYSIS OF VERIFICATION ACTIVITY (END OF 2ND YEAR)

- TEST-BED CONCURREND DESIGN SYSTEM COMBINING EXISTING CONCURRENT DESIGN METHODS AND KNOWLEDGE-BASED METHODS (END OF 2ND YEAR)

OUR GOALS

DEVELOP AN ARCHITECTURE FOR COMPUTER-AIDED CONCURRENT DESIGN

IMPLEMENT A DEMONSTRATION OF THIS ARCHITECTURE

APPLY THIS DEMO TO A REAL PRODUCT

THE ESSENCE OF THE ARCHITECTURE IS THE DESIGN OF DATA AND KNOWLEDGE BASES AND A SET OF ALGORITHMS THAT OPERATE ON THESE DB/KB'S
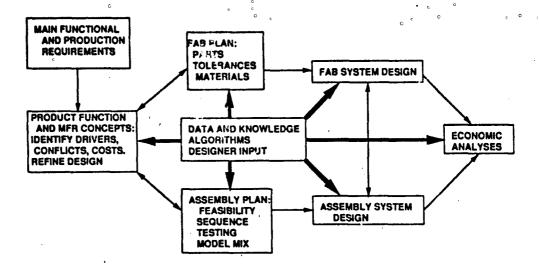
THE DB/KB'S WILL BE A MIX OF GENERIC AND PRODUCT-SPECIFIC DATA/KNOWLEDGE

THESE MUST BE OF VARIOUS TYPES, ABLE TO INTERACT WITH EACH OTHER VIA THE ALGORITHMS

THE SYSTEM MUST BE EXTENSIBLE TO ALLOW NEW ALGORITHMS, DATA AND PRODUCTS

CONCURRENT DESIGN PROCESS

```
┌──────────────────┐
│ MAIN FUNCTIONAL  │
│ AND PRODUCTION   │
│ REQUIREMENTS     │
└──────────────────┘
```

FAB PLAN:
PARTS
TOLERANCES
MATERIALS

FAB SYSTEM DESIGN

PRODUCT FUNCTION
AND MFR CONCEPTS:
IDENTIFY DRIVERS,
CONFLICTS, COSTS.
REFINE DESIGN

DATA AND KNOWLEDGE
ALGORITHMS
DESIGNER INPUT

ECONOMIC
ANALYSES

ASSEMBLY PLAN:
FEASIBILITY
SEQUENCE
TESTING
MODEL MIX

ASSEMBLY SYSTEM
DESIGN

CONCURRENT DESIGN NOW

DONE BY EXPERTS IN A TEAM

PRODUCT DESIGNERS HAVE COMPUTER TOOLS FOR AT LEAST PART OF FUNCTIONAL DESIGN

PRODUCTION DESIGNERS HAVE FEW TOOLS

ABILITY TO PREDICT EFFECT OF DESIGN ON PRODUCTION AND COST IS WEAK

PROBLEM AREAS INCLUDE MATERIALS, TOLERANCES, SPACE ALLOCATION, FAB AND ASSEMBLY
METHODS, TEST AND QC METHODS

CONCURRENT DESIGN EMERGING

DESIGN TEAMS FORTIFIED WITH COMPUTER TOOLS FOR PREDICTING

TOLERANCES

FAB METHODS, PROCESS PLANNING, AND SYSTEM DESIGN/ECONOMICS

ASSEMBLY PROCESS PLANNING, SYSTEM DESIGN, AND ECONOMICS

TESTING STRATEGY DESIGN METHODS AND ECONOMICS

CAD SOLID MODELING FOR VISUALIZATION AND AS PART OF THESE TOOLS

EXPERT SYSTEMS WITH "GENERALIZED DATA AND KNOWLEDGE" AS PART OF THESE TOOLS

CONCURRENT DESIGN OF THE FUTURE

COMPUTER HAS THE KNOWLEDGE OF THE TEAM MEMBERS

REACTS TO A DESIGNER AND EITHER COMMENTS OR WARNS

PREDICTS EFFECTS ON COST, RELIABILITY, FIELD REPAIR, ETC., AS DESIGNER REQUESTS

MUCH RESEARCH NEEDED TO ACHIEVE THIS—THE REASON FOR THIS WORKSHOP'S PANELS

LOGIC OF APPROACH

CONCURRENT DESIGN IS POTENTIALLY VERY COMPLEX

MANY KINDS OF KNOWLEDGE AND DATA MUST BE INTEGRATED

ONLY SOME OF THE DATA IS CONVENTIONAL GEOMETRIC DATA IN THE CAD SENSE

THE REST IS NON-GEOMETRIC, SOME OF IT STRUCTURED, SOME NOT

SOME CAN BE CAPTURED AS RULES, OR AS ALGORITHMS

FOR OTHER KNOWLEDGE AND DATA, WE DO NOT KNOW HOW TO REPRESENT IT

IMPLEMENTATION STRATEGY

RECOGNIZE SEMI-STRUCTURED NATURE OF PROBLEM

CHOOSE KNOWLEDGE REPRESENTATION METHOD SUITED TO GENERAL DATA

CHOOSE METHOD SUITED TO INTERFACE WITH CAD DATA

METHOD CHOSEN IS EXPERT SYSTEM SHELL

SUPPORTS OBJECT-ORIENTED REPRESENTATION AND REASONING

ALSO SUPPORTS ACCESS TO OTHER CODE (FOREIGN FUNCTIONS) TO PERMIT US TO
INTEGRATE EXISTING CSDL ALGORITHMS

KINDS OF KNOWLEDGE TO BE REPRESENTED

LOGICAL RELATIONS BETWEEN PARTS IN AN ASSEMBLY

TOPOLOGICAL RELATIONS BETWEEN THOSE PARTS

INHERITABLE PROPERTIES OF PARTS, SUBASSEMBLIES, ASSEMBLIES, FAB METHODS, ASSEMBLY
METHODS

FEATURES ON PARTS THAT ARE IMPORTANT FOR VARIOUS REASONS, SUCH AS

FUNCTION, FABRICATION, ASSEMBLY, TEST OR INSPECTION

GEOMETRIC PROPERTIES OF FEATURES AND GEOMETRIC RELATIONS BETWEEN FEATURES

IDENTITY OF SUBASSEMBLIES, PARTS COMMON TO DIFFERENT MODELS

ASSEMBLY STEPS THAT ARE EASY OR DIFFICULT TO PERFORM

METHODS OF JUDGING WHICH ASSEMBLY TECHNIQUES ARE SUITABLE TO WHICH KINDS OF PARTS
OR FEATURES

ALGORITHMS FOR DESIGNING FAB OR ASSEMBLY SYSTEMS

ALGORITHMS FOR ENUMERATING AND JUDGING ASSEMBLY SEQUENCES

ALGORITHMS FOR DESIGNING TESTING STRATEGIES

RESEARCH CHALLENGES

OBJECT-ORIENTED DATA BASE METHOD IS GENERAL BUT SEARCH IS SLOW

FORWARD/BACKWARD CHAINING TOO UNSTRUCTURED

DESIGN OF DATA/KNOWLEDGE BASE IS CRUCIAL

HELPING DESIGNER SORT OUT CONFLICTS AND FIND CAUSES FOR THE EFFECTS
WILL BE IMPORTANT BUT DIFFICULT

FORCING DESIGNER TO THINK IN TERMS OF FEATURES AS CARRIERS OF DESIGN INTENT
REQUIRES CHANGE IN DESIGN METHODS AND HABITS

MULTIPLE WAYS OF REPRESENTING THE DESIGN WILL BE NEEDED: GEOMETRY, TOPOLOGY,
POWER FLOWS, VARIANT DESIGN, FAB AND ASSEMBLY FLOWS...

SOFTWARE ARCHITECTURE OBJECTIVES AND ELEMENTS

OBJECTIVES:

ARCHITECTURE DESIGN
IMPLEMENTATION
DEMONSTRATION
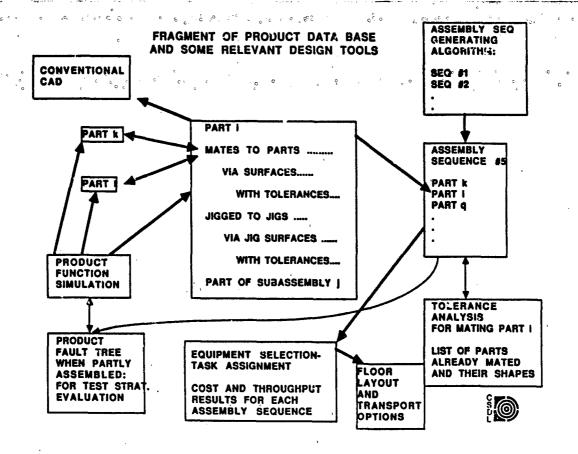
ARCHITECTURE ELEMENTS:

DATA BASES—GENERIC AND SPECIFIC
ALGORITHMS
DISPLAYS
OPERATOR INTERFACE

PLAN OF ACTION

● 1. IDENTIFY ALTERNATE DATA BASE/KNOWLEDGE BASE MECHANIZATIONS

●   IDENTIFY EXISTING COMMERCIAL SOFTWARE SHELLS FOR THIS PURPOSE—MUST BE EXTENDABLE AND CAPABLE OF INTERFACING TO SOLID MODELERS AND FOREIGN FUNCTION PROGRAMS

● 2. SURVEY LITERATURE FOR EXISTING IMPLEMENTATIONS THAT CAN BE BUILT UPON

   CONTACT VENDORS, MIT, OTHER DRAPER DEPARTMENTS

● 3. IDENTIFY HARDWARE THAT SUPPORTS THE MOST PROMISING SOFTWARE

● 4. PURCHASE HARDWARE AND SOFTWARE

5. INTEGRATE COMMERCIAL SOFTWARE AND ESTABLISH INTER-PROGRAM COMMUNICATION

◐ 6. COMPOSE TRIAL DATA/KNOWLEDGE BASES FOR ASSEMBLY KNOWLEDGE

7. TRANSFER EXISTING DRAPER ALGORITHMS ON ASSEMBLY SEQUENCES AND ASSEMBLY SYSTEM DESIGN TO THIS SYSTEM

◐ 8. IDENTIFY RESEARCH ISSUES AND OPTIONS FOR EXTENDING THE SYSTEM'S CAPABILITY

9. TEST THE SYSTEM AGAINST THE ONGOING SEEKER HEAD PROJECTS

● = DONE   ◐ = PROGRESS

FRAGMENT OF PRODUCT DATA BASE AND SOME RELEVANT DESIGN TOOLS

CONVENTIONAL CAD

ASSEMBLY SEQ GENERATING ALGORITHMS:

SEQ #1
SEQ #2
.
.

PART k

PART i

PART i
MATES TO PARTS ....
VIA SURFACES......
WITH TOLERANCES....
JIGGED TO JIGS .....
VIA JIG SURFACES ......
WITH TOLERANCES....
PART OF SUBASSEMBLY j

ASSEMBLY SEQUENCE #5

PART k
PART i
PART q
.
.
.

PRODUCT FUNCTION SIMULATION

PRODUCT FAULT TREE WHEN PARTLY ASSEMBLED: FOR TEST STRAT. EVALUATION

EQUIPMENT SELECTION- TASK ASSIGNMENT

COST AND THROUGHPUT RESULTS FOR EACH ASSEMBLY SEQUENCE

FLOOR LAYOUT AND TRANSPORT OPTIONS

TOLERANCE ANALYSIS FOR MATING PART i

LIST OF PARTS ALREADY MATED AND THEIR SHAPES

EXAMPLE DATA/KNOWLEDGE BASES

DESCRIPTIONS OF SINGLE PARTS WITH LISTS OF SURFACES THAT MATE TO OTHER PARTS AND TOLERANCES FOR SAME

A GRAPH OF THE MATES BETWEEN PARTS, WITH TYPE INFORMATION LIKE "PRESS FIT" OR "10-32 THREADS"

TRANSFORMATION MATRICES THAT RELATE PART COORDINATES TO PRODUCT BASE COORDINATES

SIMILAR MATRICES THAT INDICATE DIRECTION OF ASSEMBLY

SIMILAR MATRICES IN DIFFERENTIAL FORM TO HOLD TOLERANCE DATA

A LIST OF POTENTIAL GRIP AND JIG SURFACES FOR EACH PART

A LIST OF POTENTIAL ASSEMBLY EQUIPMENT

A CROSS-REFERENCED LIST OF WHAT EQUIPMENT IS APPLICABLE TO WHICH ASSEMBLY TASKS

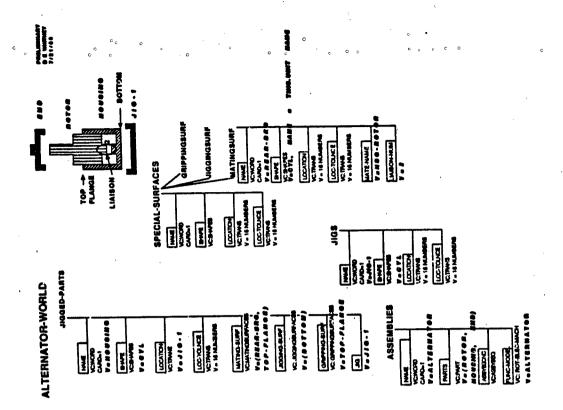A LIST OF FEASIBLE ASSEMBLY SEQUENCES FOR THE PRODUCT

RULES AND LOGICAL/NUMERICAL PROCEDURES FOR FINDING ASSEMBLY SEQUENCES

3D GEOMETRIC MODELS OF THE PARTS

FAULT TREES FOR THE PRODUCT WHEN PARTIALLY ASSEMBLED

EXAMPLE DATA/KNOWLEDGE BASES

PRODUCT BASE

LIAISON DIAGRAM

FEASIBLE ASSEMBLY SEQUENCES

LIAISON 3
LIAISON 1
PART A BASE

LIAISON 2
LIAISON 1
PART B BASE

LIAISON 2
LIAISON 3
PART C BASE

LIAISON 3
LIAISON 1
PART A BASE

LIAISON 2
LIAISON 1
PART B BASE

LIAISON 2
LIAISON 3
PART C BASE

ASSEMBLIES KNOWLEDGE BASE

PRELIMINARY
D E WHITNEY
7/31/88

SOFTWARE ARCHITECTURE

MUST SUPPORT THE FOLLOWING CAPABILITIES
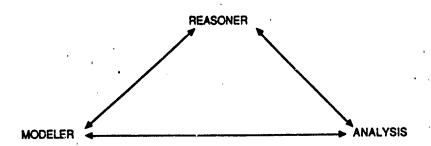
    DESIGN

    REASONING

    ANALYSIS
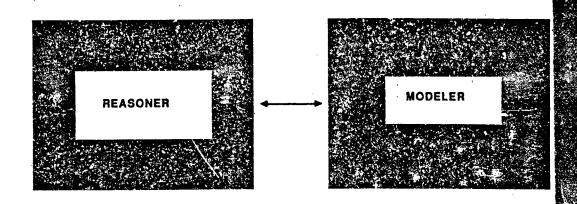
MUST ALLOW COMMUNICATION BETWEEN MODULES

FEATURES REPRESENT THE PRIMARY DATA

IDEAL

REASONER

MODELER ←————————————→ ANALYSIS

BLACK BOXES

REASONER ←————→ MODELER

COMMUNICATION

IDEAS —————————————KEE ————————————————— ANALYSIS

UNIX UTILITIES   FOREIGN FUNCTION CALLS

CAPABILITIES

DESIGN   SDRC IDEAS   SOLIDS
                                               ASSEMBLY
                                               FEATURES

REASONING   KEE   INFERENCE ENGINE

                                               CUSTOMIZED KNOWLEDGE BASES

ANALYSIS   LSA
                  ASDP
                  FABRICATIOIN
                  PART MATING
                  ASSEMBLY PLANNING
                  KINEMATICS
                  TOLERANCE

FEATURES COMPRISE THE LANGUAGE OF RULES

IF THE HOLE IS TOO CLOSE TO THE EDGE , THEN MOVE THE HOLE

GEOMETRIC REPRESENTATION OF HOLE (FORM FEATURE) MAY BE
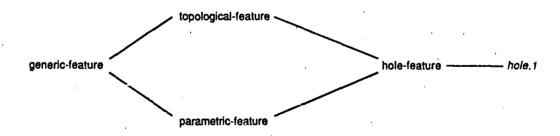
CYLINDER (SOLID)

CIRCLE (WIREFRAME)

GEOMETRY BASED DISTANCE FUNCTION NEEDED TO DETERMINE 'TOO CLOSE'
(BLACK BOX APPROACH MAY PREVENT ACCESS OF MODELER DISTANCE FUNCTION)

GEOMETRY ONLY IMPLICITLY REFERENCED FOR FORM FEATURES

GEOMETRY MAY BE IRRELEVANT FOR OTHER FEATURES

FEATURE DATA STRUCTURE

```
                    topological-feature
                   /                    \
generic-feature                          hole-feature ————— hole.1
                   \                    /
                    parametric-feature
```

FEATURES INTO DATA BASE/KNOWLEDGE BASE

CONSTRUCT WITH FEATURES

IDENTIFY FEATURES (REQUIRES USER INTERVENTION)

RECOGNIZE FEATURES AUTOMATICALLY

CONSTRUCT WITH FEATURES

+ CONSISTENCY OF GEOMETRY WITH PARMETERS

GEOMETRY DERIVED DIRECTLY FROM PARAMETERS

- MODEL UNSTABLE

INTERNAL GEOMETRY DATA BASE POINTERS CHANGE WITH EDITS

IDENTIFY FEATURES

+   MODEL ASSUMED COMPLETE

            INTERNAL GEOMETRY DATA BASE POINTERS FIXED

-     POTENTIAL INCONSISTENCY OF PARAMETERS WITH GEOMETRY

            RELIES UPON USER INPUT OF PARAMETERS

            RECOGNIZE FEATURES AUTOMATICALLY

+   PARAMETERS CONSISTENT WITH GEOMETRY

                  PARMATERS DERIVED DIRECTLY FROM GEOMETRY

-     MANY NARROW DOMAIN SPECIFC EXPERT SYSTEMS

SYNCHRONIZATION OF GEOMETRY DATA BASE AND FEATURE KNOWLEDGE BASE

KNOWLEDGE BASE ONLY GUARANTEED IN SYNCHRONIZATION UPON INITIAL READ/WRITE

KNOWLEDGE BASE MUST KNOW WHEN MODEL CHANGES

INCREMENTAL/DECREMENTAL UPDATE SEEMS IMPOSSIBLE WITHOUT UNIQUE EXTERNAL

GEOMETRY IDENTIFIERS

TWO ALGORITHMS TO BE INTEGRATED WITH KNOWLEDGE BASES

EQUIPMENT SELECTION AND TASK ASSIGNMENT FOR DESIGN OF FABRICATION OR
ASSEMBLY SYSTEMS

LIAISON SEQUENCE ANALYSIS FOR DETERMINING FEASIBLE ASSEMBLY
SEQUENCES AND CHOOSING A GOOD ONE

EQUIPMENT SELECTION AND TASK ASSIGNMENT

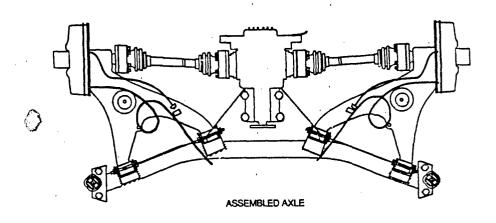TWO FAMILIES OF ALGORITHMS, ONE OPTIMAL, ONE HEURISTIC

EACH ONE SOLVES THE FOLLOWING PROBLEM

GIVEN
AN ASSEMBLY SEQUENCE
POSSIBLE WAYS OF DOING EACH ASSEMBLY TASK--ROBOT, PERSON, ETC.
THE TIME AND COST OF EACH WAY
A LIST OF NECESSARY TOOLS FOR EACH TASK FOR EACH WAY
COST OF TOOLS AND TIME TO CHANGE TOOLS
TIME TO MOVE WORK INTO OR OUT OF THE WORKSTATIONS
THE REQUIRED PRODUCTION VOLUME

FIND THE BEST WAY OF DOING EACH TASK

ASSEMBLED AXLE

TITLE IRS Rear Axle **DATE** 5/6/88

235	WORKING DAYS/YEAR
2	SHIFTS AVAIL
5	SEC STA-STA MOVE TIME

0.2395	ANN COST FACTOR
$20/hr	AVG LOADED LABOR RATE
900,000	Annual Production Vol.

RESOURCE DATA SET NAME

TASK DATA SET NAME

FOR EACH RESOURCE | OPERATION TIME (S) | TOOL NUMBER

C HARDWARE COST
ρ INST/HARDW COST
v UPTIME EXPECTED
tc OP/MAINT RATE $/HR
tc SEC TOOL CHANGE TIME
ms MAX STA/WORKER

HARDWARE COST ($)

RESOURCE / TASK	Manual	Fixed	Small Robot	Big Robot
	C 600	C 0	C 50000	C 80000
	ρ 1.5	ρ 1.5	ρ 35	ρ 35
	v 80	v 95	v 90	v 90
	tc 5	tc 5	tc 5	tc 10
	ms 83	ms 4	ms 4	ms 3
1. Put frame on pallet	10 | 101 15000	7 | 201 75000	✕	10 | 401 15000
2. Attach body / mount to frame	25 | 102 2000	7 | 202 100000	20 | 302 90000	15 | 402 90000
3. Subassemble / Shafts to A-Arms	40 | 103 30000	15 | 203 200000	✕	35 | 403 90000
4. Attach A-Arms / To frame	30 | 104 2000	15 | 204 200000	✕	20 | 404 90000
5. Place Differential on frame	10 | 105 5000	10 | 205 100000	✕	8 | 405 20000
6. Mate Diff / Shafts, frame	40 | 106 15000	20 | 206 250000	✕	35 | 406 125000

IRS REAR AXLE-300K-CONV-1 AX/PALLET

33.33 seconds Usable Cycle Time
90.0 x Bottleneck up-time   108.00 Units/hr expected
406080 units Actual Capacity of this System

1433000 ($) Total Investment, rho Factor = 1.58
3.06 Workers at 26.00 $/hr required
46.00 $/hr System Operating/Maintenance Rate

0.739 Year required for 2.0 Shift Operation
235 Days required for 1.48 Shift Operation

300000 Units $3.258 Each   235 Days
33.3s Cycle Time   2.0 Shifts   0.810 AF

1 FXD 15.8s	2 FXD 21.1s	3 RBS + 33.3s	4 RBS + 27.8s	5 MAN 25.0s
6 FXD 26.3s	7 MAN 28.1s *2	8 TRN 10.1s		

LIAISON SEQUENCE ANALYSIS PRIMER

LIAISON SEQUENCE ANALYSIS IS A SYSTEMATIC WAY TO GENERATE
ALL THE FEASIBLE ASSEMBLY SEQUENCES FOR A PRODUCT

THE PROCEDURE IS:

1. IDENTIFY LIAISONS BETWEEN PARTS

2. ANSWER A SERIES OF QUESTIONS

3. WRITE PRECEDENCE RELATIONS FROM THE ANSWERS

4. USE THE RELATIONS TO GENERATE A NETWORK OF FEASIBLE SEQUENCES

5. EDIT THE RESULTING NETWORK TO OBTAIN A FEW GOOD SEQUENCES

LIAISONS ARE RELATIONS BETWEEN PARTS

TOUCH, PRESS FIT, THREAD FIT, ETC.

LIAISON DIAGRAMS SHOW CONNECTIONS BETWEEN PARTS

LIAISON SEQUENCES ARE SIMILAR TO ASSEMBLY SEQUENCES

DIFFERENCES ARE:

A LIAISON SEQUENCE LISTS THE MATES IN SEQUENCE

AN ASSEMBLY SEQUENCE LISTS THE PARTS IN SEQUENCE

IN LIASON SEQ ANALYSIS THERE IS NO "FIRST PART," BUT
INSTEAD THERE IS A FIRST LIAISON

LIAISON SEQUENCE ANALYSIS PRIMER-3

LIAISON SEQUENCE NETWORK

PRECEDENCE RELATION

3 > 7 & 9

LIAISON 3
DONE

LIAISON 11
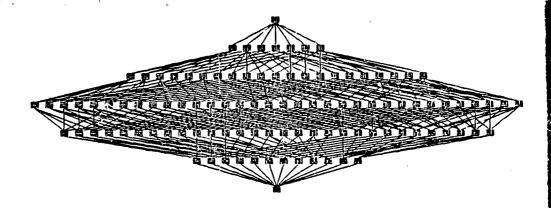DONE

(EVENTUALLY)
ALL LIAISONS
DONE

Figure 20. A graph of complete assembly sequences (a total of 1528) generated from a liaison diagram (Figure 18) and PR (Figure 19).
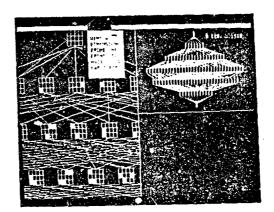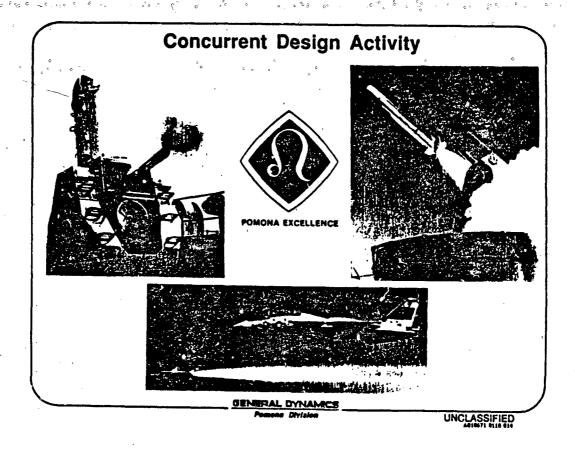

Figure 24. The design of the display of the developing software system.

GENERAL DYNAMICS - POMONA DIVISION

AND

MARTIN MARIETTA MISSILE SYSTEMS CO.

**SUPPORT TO THE DARPA-CSDL PROGRAM
EXPERT SYSTEMS FOR MANUFACTURING
OF SMART WEAPONS COMPONENTS**

Concurrent Design Activity

POMONA EXCELLENCE

GENERAL DYNAMICS
Pomona Division
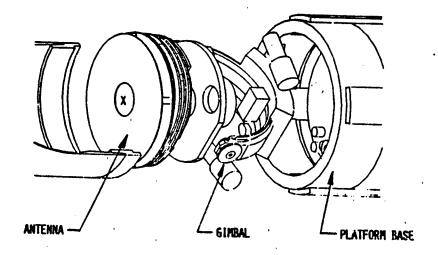
TYPICAL AEROSPACE VEHICLE SEEKER

- PROVIDES STABLE PLATFORM FOR GUIDANCE SENSOR

- COMPLEX ELECTRO-MECHANICAL DEVICE : "SYSTEM BRAIN"

- TOLERANCES ARE CRITICAL TO FUNCTIONAL NEEDS OF DESIGN

- SYSTEM TESTING IS BOTH FUNCTIONAL AND DYNAMIC

- PRODUCT COST, QUALITY, RELIABILITY, PERFORMANCE ARE

  COMPLEX INTERRELATED PARAMETERS

- -

- NEEDS OF FUTURE WEAPON SYSTEM DRIVE THE SEEKER TO

  BOUNDARIES OF THE ACHIEVABLE

ANTENNA ————— GIMBAL ————— PLATFORM BASE
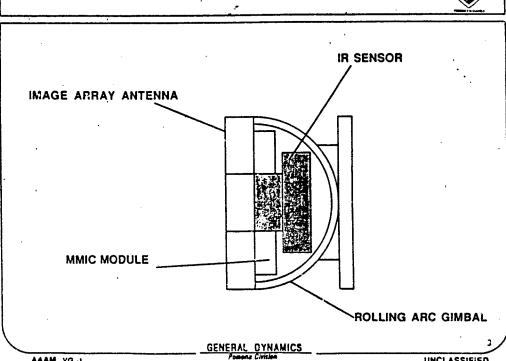
RF/IR DUAL MODE COMMON APERTURE SEEKER

IR SENSOR

IMAGE ARRAY ANTENNA

MMIC MODULE

ROLLING ARC GIMBAL
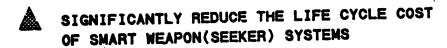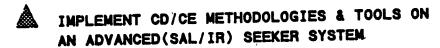
DARPA EXPERT SYSTEMS
for MANUFACTURING of SMART
WEAPONS COMPONENTS

▲ **CSDL/MARTIN MARIETTA**
   SAL/IR SEEKER
   CONCURRENT ENGINEERING
   EFFORT

CD1

PROGRAM OBJECTIVES

▲ SIGNIFICANTLY REDUCE THE LIFE CYCLE COST
  OF SMART WEAPON(SEEKER) SYSTEMS

▲ IMPLEMENT CD/CE METHODOLOGIES & TOOLS ON
  AN ADVANCED(SAL/IR) SEEKER SYSTEM

▲ TRANSITION THESE CD/CE METHODOLOGIES &
  TOOLS TO MARTIN MARIETTA MISSILE
  SYSTEMS PROGRAMS

                                              002

PROGRAM STATUS
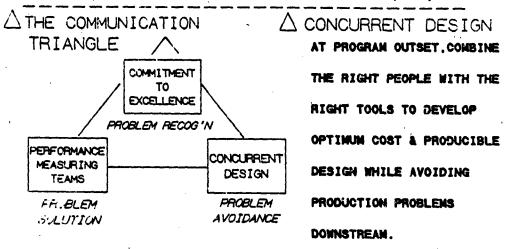
▲ ACCOMPLISHMENTS(AUG-DEC 1988)
  O CSDL HAS RECEIVED/REVIEWED OTHER SEEKER
    (HELLFIRE/CH) DOC'N TO INITIATE DATABASE

  O CSDL HAS TOURED HELLFIRE & CH SEEKER
    ASSEMBLY & TEST LINES

  O CSDL HAS RECEIVED PRELIM SAL/IR SEEKER DESIGN
    INF. & PERTINENT COMPANY ECONOMIC DATA
         DEWAR/DETECTOR SUBASS'Y REQ'TS
         GIMBAL SUBASS'Y REQ'TS
         OPTICS REQ'TS

▲ FUTURE PLANS(JAN 1989-)

  O MARTIN MARIETTA WILL ESTABLISH A TEAM T. WORK
     WITH CSDL & INDEPENDENTLY TO IMPLEMENT LIFE
     IN SAL/IR & OTHER SEEKER PROGRAMS THRU COMPANY
     SPONSORED & IRAD PROGRAMS   003

MARTIN MARIETTA MISSILE SYSTEMS
PRODUCTION OPERATIONS/
TECHNOLOGY & SYSTEMS ENGINEERING(TSE)
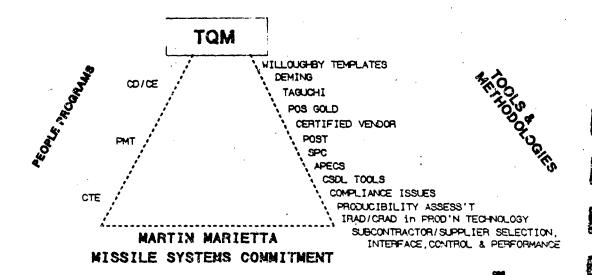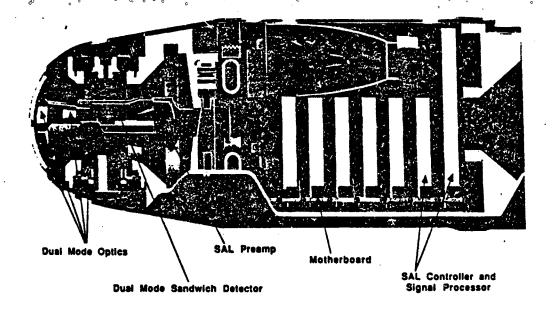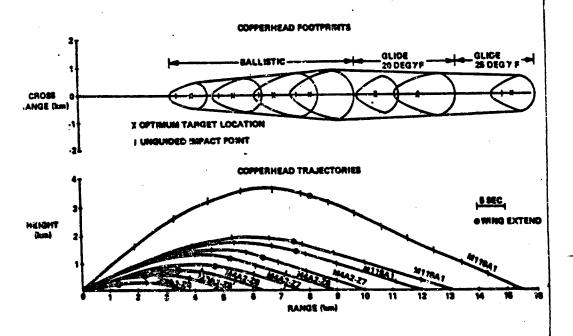
△THE COMMUNICATION TRIANGLE

```
              COMMITMENT
                  TO
              EXCELLENCE
            PROBLEM RECOG'N
  PERFORMANCE            CONCURRENT
  MEASURING                DESIGN
    TEAMS
    FROBLEM                PROBLEM
   SOLUTION               AVOIDANCE
```

△ CONCURRENT DESIGN

AT PROGRAM OUTSET, COMBINE

THE RIGHT PEOPLE WITH THE

RIGHT TOOLS TO DEVELOP

OPTIMUM COST & PRODUCIBLE

DESIGN WHILE AVOIDING

PRODUCTION PROBLEMS

DOWNSTREAM.

CD4

FOUNDATION — ESSENTIAL ELEMENTS for IMPLEMENTING TQM

```
              TQM
                           WILLOUGHBY TEMPLATES
         CD/CE               DEMING
                              TAGUCHI
                               POS GOLD
                                CERTIFIED VENDOR
         PMT                     POST
                                 SPC
                                  APECS
                                   CSDL TOOLS
    CTE                             COMPLIANCE ISSUES
                                   PRODUCIBILITY ASSESS'T
                                  IRAD/CRAD in PROD'N TECHNOLOGY
                                 SUBCONTRACTOR/SUPPLIER SELECTION,
         MARTIN MARIETTA            INTERFACE, CONTROL & PERFORMANCE
    MISSILE SYSTEMS COMMITMENT
```

PEOPLE PROGRAMS

TOOLS & METHODOLOGIES

CD4

SAL/I^{2}R

Dual Mode Optics

SAL Preamp

Motherboard

SAL Controller and
Signal Processor

Dual Mode Sandwich Detector

UNCLASSIFIED
COPPERHEAD ENGAGEMENT ENVELOPE

COPPERHEAD FOOTPRINTS

BALLISTIC — GLIDE 20 DEG γ F — GLIDE 25 DEG γ F

CROSS RANGE (km)

X OPTIMUM TARGET LOCATION

I UNGUIDED IMPACT POINT

COPPERHEAD TRAJECTORIES

5 SEC

● WING EXTEND

HEIGHT (km)

RANGE (km)
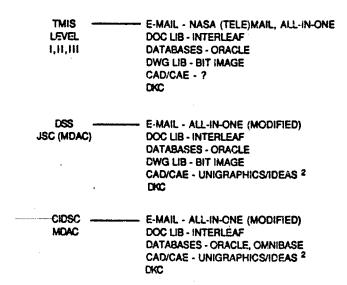
NASA-JSC SPACE STATION PROGRAM USE OF CE

① WPA PARTITIONING OF PROGRAM CAUSES LIMITED CE "TEAMS"

```
                        ┌─────────┐
                        │ LEVEL I │
                        └─────────┘
                             │
                        ┌──────────┐
                        │ LEVEL II │
                        └──────────┘
                             │
         ┌──────────┬────────┼──────────────┬──────────┐
      ┌──────┐   ┌─────┐            ┌──────┐       ┌──────┐
LEVEL III │ MSFC │   │ JSC │            │ GSFC │       │ LeRC │
      └──────┘   └─────┘            └──────┘       └──────┘
         │    ┌──────┬─────────────────┼──────────────┐
      ┌─────┐      ┌────────┐      ┌─────┐        ┌───────┐
      │ KSC │      │ CANADA │      │ ESA │        │ NASDA │
      └─────┘      └────────┘      └─────┘        └───────┘
         │
      ┌──────┐
      │ MDAC │
LEVEL IV └──────┘
         │
   ┌──────────┬──────────┬──────────┐
┌──────────┐ ┌─────┐  ┌─────┐    ┌─────┐
│ LOCKHEED │ │ IBM │  │  ~  │    │  ~  │
└──────────┘ └─────┘  └─────┘    └─────┘
```

② CE "TOOLS" - SEMI-INTEGRATED

TMIS LEVEL I,II,III	E-MAIL - NASA (TELE)MAIL, ALL-IN-ONE DOC LIB - INTERLEAF DATABASES - ORACLE DWG LIB - BIT IMAGE CAD/CAE - ? DKC
DSS JSC (MDAC)	E-MAIL - ALL-IN-ONE (MODIFIED) DOC LIB - INTERLEAF DATABASES - ORACLE DWG LIB - BIT IMAGE CAD/CAE - UNIGRAPHICS/IDEAS [2] DKC
CIDSC MDAC	E-MAIL - ALL-IN-ONE (MODIFIED) DOC LIB - INTERLEAF DATABASES - ORACLE, OMNIBASE CAD/CAE - UNIGRAPHICS/IDEAS [2] DKC

③ IMPRESSIONS

A. I'M SOLD (OR BRAINWASHED)
   BUT,

   - HOW DO I SELL JSC
   - WHO SELLS NASA & OTHER A_ _ _ _ _ _

B. I'M SOLD (BUT CONFUSED)
   HOW IS RESEARCH

   - DELEGATED
   - COORDINATED
   - INTEGRATED
   - EVALUATED
   - COMMUNICATED
   - DOCUMENTED

C. PROPOSAL

   - FUND CE MANAGEMENT STUDY
   - DEVELOP U.S. IMPLEMENTATION PLAN
   - USE CE TO DEVELOP CE

CAD	DATABASE
CAD	CAD

INDUSTRIAL PROGRAMS

BOEING AEROSPACE CORPORATION BSD

"DEVELOPMENTAL OPERATIONS (DO)" PROGRAM

NB 8453

What is DO?

Ballistic Systems Division

- **DO IS** . . . an internal Boeing Aerospace-wide "renewal" process intended to regain our competitive edge and maintain our aerospace leadership

- **Uses proven** . . . "process management" techniques to examine and simplify existing processes using problem-solving/team-building techniques

- **Emphasis on** . . . execution plans that provide substantial efficiency and quality gains in an environment of cultural change

Why Do We Need to Change The Process?
Ballistic Systems Division

● **We evolved** . . . over past 25 or so years, a system of procedures to ensure consistency in design, change control, manufacturing, procurement, quality, etc.

● **Formal and rigorous** . . . procedures, directives, specifications, etc . . . audit findings and problems increase complexity . . . interpretation more severe with every passing year

● **Bureaucracy evident** . . . more procedures, more groups to administer, more "improvements" by respective functions. . . overhead and DD charges grew as did number and degree of crosschecks . . . efficiencies suffered resulting in new business losses

● **Shrinking DOD market** . . . strong competition—fewer new production starts . . . need for bottom-line performance on R&D contracts and, most recently, DOD emphasis on quality

NB4463N1-MC-10/12/88R4
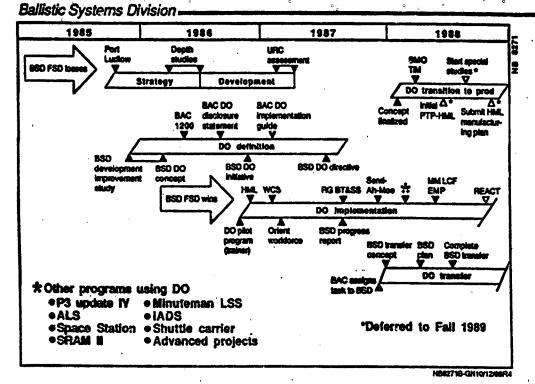
Our Strategies Were Simple
Ballistic Systems Division
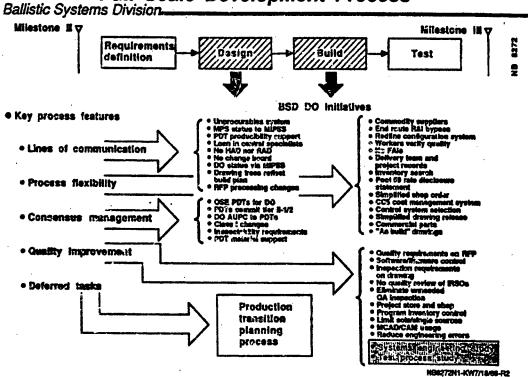
● Development of low tech, easy to maintain wheeled vehicle suitable for desert or Northern Tier operation . . . use of commercial parts wherever possible . . . user friendly

● A bid strategy and **execution process** yielding cost and schedule reductions at least 1/3 less than traditionally achieved

● Develop and use of an **integrated team concept**

NB8743N1-MC-10/19/88R1

Developmental Operations (DO) — a New More Flexible/ Responsive "Design-Build-Test" Process for Development

Ballistic Systems Division

* Other programs using DO
  * P3 update IV
  * ALS
  * Space Station
  * SRAM II
  * Minuteman LSS
  * IADS
  * Shuttle carrier
  * Advanced projects

*Deferred to Fall 1989

Process Management Examination of Total Full Scale Development Process

Ballistic Systems Division

* Key process features
* Lines of communication
* Process flexibility
* Consensus management
* Quality improvement
* Deferred tasks

DO "Systems Engineering" and "Test" Process Management Effort Underway
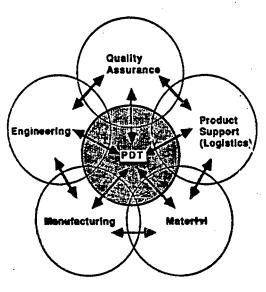
Ballistic Systems Division

▽ Milestone II   Milestone III ▽

```
Systems
engineering  →  Design  →  Build  →  Test
```

```
Form
Team  →  Create
"as-is"
model  →  Develop
"should-be"
model  →  Document
and begin
implementation
```

• Select members	• Build strawman	• Finalize issues (C)	• Develop implementation schedule (10%)
• Define charter	• Identify concerns	• Identify and prioritize initiatives (30%)	• Begin implementation process (10%)
• Define tasks and objectives	• Finalize model	• Assign responsibility (C)	• Draft/publish media
	• Finalize barriers and concerns	• Plan and schedule implementation (20%)	• Complete project

10/19/87   11/18/87   2/19/88   6/1/88   12/1/88

- **Highlights**
  - (6) sub teams/(7) issues
  - (346) barriers and concerns
  - (30) initiatives established with (8) being piloted

NB8273N1-KW3/28/88-R1

Product Development Teams...
"Multi-Disciplinal Team Emphasis Throughout Requirements/Design/Build/Test Process"

Ballistic Systems Division

Quality Assurance · Engineering · Product Support (Logistics) · PDT · Manufacturing · Materiel
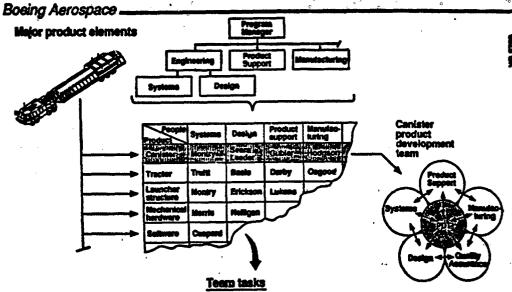
- **What is a PDT?**
  - Team of functional representatives who have as their common purpose the concurrent development of a given product from inception through product delivery and support
- **Key features**
  - Hardware element ownership
    - Responsibility and authority
    - AUPC cost goals
  - Key decisions, conflict resolution, guidance... C.E. or product development manager or council
  - Team training
    - Member behavior
    - Team qualities
    - Consensus and group process
    - Brainstorming and creativity, etc.

NB820681-GN 10/12/88-R3

How PDTs Work

Major product elements

Canister product development team

Team tasks

- Evaluate requirements and conduct trades
- Allocate and manage average unit production cost
- Review and approve designs
- Develop quality requirements

- Develop and commit schedules
- Order materials
- Develop test plans
- Monitor status and provide fabrication support
- Maintain configuration and delivery data package

NB0790NB1-KO 11/22/89-R1

Comparison PDTs to DBTs
"Beware—They're Not The Same"

Product Development Teams (PDTs)	Design/Build Teams (DBTs)
● Chartered and engaged before RFP..................DNA	
● Review and suggest improvements to......*......Review and suggest inprovements to	
● Product requirements..................................DNA	
● Design constraints..................................DNA	
● Design solutions..................................*..........Design solutions	
● Make/buy determination, buy and building planning..................................Buy and build planning only	
● Develop product, system and weapon system test plans...........................DNA	
● Plan and commit product schedules..................DNA	
● Plan and control charges..................................DNA	
● Establish quality requirements..................DNA	
● Maintain active program status and action logs..................................DNA	
○ Operate in concert with other PDTs to develop total product..................*......Single purpose task team (develop satisfy short range objectives, and discontinue effort	
● Targeted cost goals—program life cycle..................................*......Targeted cost goals—design/build only	
● Product configuration and delivery responsibility..................................DNA	
● Program status reporting..................DNA	

★ Similar   DNA—Does Not Apply

NB 8742

NB 8742-BSD/AS-10/19/88 R2

DOD Acquisition Policy Changes Being Studied

- **President's Blue Ribbon Commission on Defense Management notes, "weapon systems take too long to develop, cost too much to produce, and often do not perform as promised or expected"**

- **OSD perceptions**

  - **"higher quality can result in lower cost and shortened schedules . . ."**

  - **"concurrent development and qualification permits multifunctional trades to be made in a timely manner in pursuit of optimum balance of capability, cost, and schedule"**

  - **What is Concurrent Engineering - A systematic approach to create product designs that consider all elements of the product life cycle . . . "simultaneously" defining product requirements, the product, its manufacturing process, and required life cycle processes**

Results Are In And Are Truly Amazing!

- **Schedule performance has been outstanding**

  - **All major hardware-related events on or ahead of schedule . . . from factory BOD July 15, 1987 to last hardware item ondock October 10, 1988**

  - **(37) major OSE, MHE and test aids designed, developed and delivered using "real time" schedules averaging 1/3 less flow time than "standard"**

  - **No. 1 launcher less than 10 months to assemble, test and integrate . . . jig load December 8, 1987 to September 30, 1988 rollout**

  - **Overall use of "quick acquisition process" resulted in 70% of all parts and materials in stores within 5 days of request**

Results Are In And Are Truly Amazing!
(Continued)

Ballistic Systems Division

● **Cost performance has been outstanding**

- ● **16% cum underrun in contract—recurring hardware costs (with 30% proposal reductions—46% over "traditional")**

- ● **Unit two hardware 20% less than first unit actuals (at termination)**

- ● **Equivalent reductions in division DD, OH and wrap rates (using DO process and pool 59 disclosure) . . . improved division efficiencies for follow-on efforts**

- ● **33% savings in engineering "production support" labor**

NB0746N1-MC-10/18/88R1

Results Are In And Are Truly Amazing!
(Continued)

Ballistic Systems Division

● **And we did it in an atmosphere of openness and trust**

- ● **Employed team building/consensus management techniques**

- ● **Encouraged customer understanding, support and participation**

- ● **Used simplified, flexible, responsive processes to execute all "design-build-test" activities**

- ● **Recognized and folded in major subcontractors as "critical to the process" . . . encouraged participation and rewarded execution and ownership**

- ● **Stamped out functional barriers/advocacy and acknowledged team performance**

NB0746N1-MC-10/18/88R1

Results Are In And Are Truly Amazing!
(Continued)

Ballistic Systems Division

- **Quality of product and effort was outstanding**

  - Error-free engineering initiatives excellent . . . yielded 1.04 redline changes per drawing sheet (Peacekeeper average 15.3)

  - Hundreds of net-sized parts with full-size Class I holes . . . nearly error-free

  - Cost of quality reduced 60% (80% in factory) while maintaining excellent quality standards—99% defect-free performance

  - De-emphasize policing . . . focus on quality as a tangible, observable product (plan-in and build-in) . . . elimination of paper barriers and complicated procedures

  - Team ownership of requirements, products, and delivery efforts . . . zero AFCMD forms 921 and 1127

  - Customer quality "health" indicators highest ever realized (September 1988—4.8)

NB6747N1-MC-10/16/88R1

Summary

Ballistic Systems Division

- Process is ongoing . . . now migrating selectively throughout Boeing Aerospace

- Each division (program) must determine its own needs . . . cultural transformation necessary . . . how to meet unique customer desires/needs

- Our DOD customer understands and is considering acquisition policy changes

- Resistance to change can be very strong and takes a great deal of posturing, time and attention (to beat out old habits)

- Real challenge is transforming functional players into program "team" players . . . supported by top-down management willingness to change, permissiveness, flexibility, and acceptance of risk

- Process of "change" is very difficult but can be highly rewarding . . . don't wait to be mandated—get actively involved . . . you owe it to yourself

NB 8724N81-MC10/12/88R1

IBM "TOTAL CONCEPT FACILITY"

FOR THE DESIGN OF MAINFRAME COMPUTERS

SYSTEM PACKAGING

MISSION

- PROVIDE MECHANICAL DESIGN TO HOUSE THE ELECTRONICS

- PROVIDE SIGNAL AND POWER CABLE TECHNOLOGY AND DESIGN

- ASSURE PRODUCT SAFETY

- PROVIDE PRODUCT INSTALLATION DOCUMENTS

- ASSURE AVAILABILITY AND PROPER USE OF STANDARDS

- BUILD EARLY MODELS

- PROVIDE DESIGN DOCUMENTS TO MANUFACTURING

KD DURFEE-12/88

DRIVING FORCES

- 3090 HISTORY

- QUALITY

- PRODUCTIVITY

- SHORTENED DESIGN CYCLE

- REDUCED PRODUCT COST (INITIAL COST AND ECs)

- IN SUMMARY: PRODUCE A COMPETITIVE PRODUCT

KD SURFEE-12/88
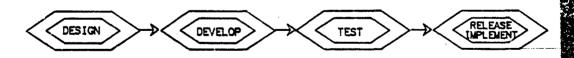
TOTAL CONCEPT FACILITY (TCF)

OBJECTIVE:

JOINT PRODUCT AND PROCESS DEVELOPMENT FROM DESIGN THROUGH RELEASE

P R O D U C T

DESIGN → DEVELOP → TEST → RELEASE/IMPLEMENT

P R O C E S S

SYSTEM PACKAGING

DESIGN "TOOLS"

- DEPARTMENT ACTIVITY ANALYSIS

    - INPUTS (REQUIREMENTS)
    - OUTPUT (DOCUMENTED RESPONSE)

- EARLY MANUFACTURING INVOLVEMENT

- DESIGN REVIEWS

- ELECTRONIC DESIGN TOOLS

    - 3D (DESIGN)
    - 2D (RELEASE)
    - ANALYTICAL
    - RELEASE

- DATA BASES

    - STANDARD PARTS
    - DESIGN STANDARDS
    - PAST PROBLEMS
    - CURRENT DISCOVERIES
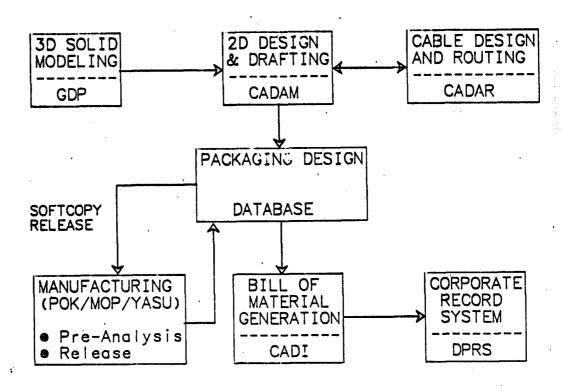
- MANAGEMENT (TRACKING) TOOLS
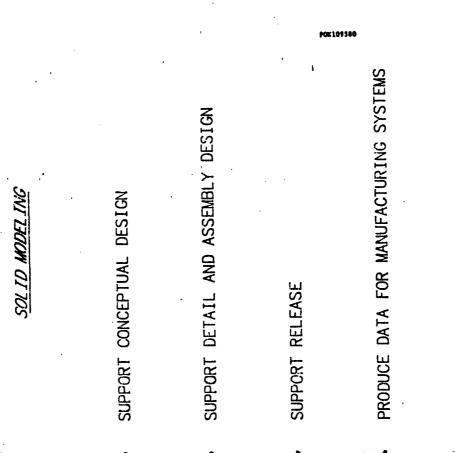
    - DESIGN SCHEDULE
    - PARTS: QUANTITY AND SCHEDULE
    - MODELING SCHEDULE
    - COST
    - DISCOVERIES: QUANTITY AND SCHEDULE
    - ECs

KD DURFEE-12/88

SYSTEM PACKAGING DESIGN PROCESS

- REQUIREMENTS STAGE

    - "CUSTOMER" - "SUPPLIER" APPROACH
    - DEFINE COMPETITIVE PRODUCT
    - SET OBJECTIVES (COSTS, NO. OF PARTS, ECs, SCHEDULES)
    - DEFINE MEASUREMENT PLAN

- CONCEPT STAGE

    - 3D "FOOTPRINT" LAYOUTS

- COMPONENT MODEL

    - 3D/2D BEGIN DETAILED DESIGN
    - MODEL (WOOD, ETC.) CRITICAL PARTS

- DETAILED DESIGN

    - COMPLETE 3D/2D DETAILED DESIGN
    - BUILD EARLY MODELS
    - DEVELOPMENT RELEASE

- FORMAL RELEASE

    - RELEASE DESIGN TO WORLD-WIDE MANUFACTURING
    - QUALIFY COMPONENTS
    - START PRODUCT ENGINEERING

KD DURFEE-12/88

MECHANICAL DESIGN FLOW

```
┌──────────────┐        ┌──────────────┐        ┌──────────────┐
│ 3D SOLID     │        │ 2D DESIGN    │        │ CABLE DESIGN │
│ MODELING     │───────▶│ & DRAFTING   │◀──────▶│ AND ROUTING  │
│ ─────────    │        │ ─────────    │        │ ─────────    │
│    GDP       │        │   CADAM      │        │   CADAR      │
└──────────────┘        └──────────────┘        └──────────────┘
                               │
                               ▼
                    ┌──────────────────┐
                    │ PACKAGING DESIGN │
                    │                  │
                    │    DATABASE      │
                    └──────────────────┘
      SOFTCOPY      │                  │
      RELEASE       │                  │
                    ▼        ▲         ▼
┌──────────────────┐│   ┌──────────────┐      ┌──────────────┐
│ MANUFACTURING    │   │ BILL OF      │      │ CORPORATE    │
│ (POK/MOP/YASU)   │   │ MATERIAL     │      │ RECORD       │
│                  │──▶│ GENERATION   │─────▶│ SYSTEM       │
│ ● Pre-Analysis   │   │ ─────────    │      │ ─────────    │
│ ● Release        │   │   CADI       │      │   DPRS       │
└──────────────────┘   └──────────────┘      └──────────────┘
```

SOLID MODELING

- SUPPORT CONCEPTUAL DESIGN

- SUPPORT DETAIL AND ASSEMBLY DESIGN

- SUPPORT RELEASE

- PRODUCE DATA FOR MANUFACTURING SYSTEMS

KD DURFEE-12/88

TOTAL CONCEPT FACILITY RESULTS

(a.k.a. Concurrent Engineering)

IBM POUGHKEEPSIE DEVELOPMENT LABORATORY

LARGE SYSTEMS MECHANICAL/POWER/THERMAL DESIGN

	TRADITIONAL APPROACH	TOTAL CONCEPT FACILITY IMPROVEMENT *	FUTURE PROJECTION
UNIQUE PART NUMBERS	1.0	.50	.29
ENGINEERING CHANGES	1.0	.41	.18
ASSEMBLY HOURS	1.0	.55	TBD

* IMPROVEMENT IS THE RESULT OF BOTH "CONCURRENT ENGINEERING" AND IMPROVED 3D DESIGN AND ANALYSIS TOOLS

KD DURFEE-12/88

SOLID MODELING TOOLS

- VISUAL ANALYSIS
- INTERFERENCE ANALYSIS
- TORQUE ANALYSIS
- FASTENER ANALYSIS
- TOLERANCE ANALYSIS
- STABILITY ANALYSIS
- INDUSTRIAL DESIGN ANALYSIS
- BILL OF MATERIALS ANALYSIS
- ASSEMBLY COST ANALYSIS
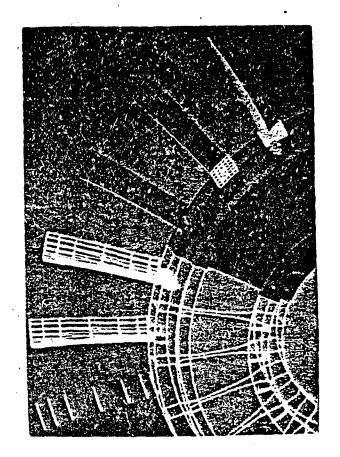
KD DURFEE-12/88

P & W GMAP PROGRAM

G Geometric
M Modeling
A Applications
P Interface Program

GMAP

- Sponsored by USAF
  Manufacturing Technology Directorate

- Pratt & Whitney prime

- GMAP contract duration

  Aug 85 ———► Aug 88 ———————► Jul 89
  └── original ──┘ └── extension ──┘

GMAP TERMINOLOGY:

Product Definition Data (PDD):

Information which completely defines a product component or assembly to the extent that the product:
— design intent is fully represented
— can be analyzed
— can be manufactured and inspected
— can be supported after manufacture

Product life cycle:

The functional areas that span initial product concept to retirement. This includes design, analysis, manufacturing, inspection, product and logistic support.

A VISION FOR PDD IN THE 1990s
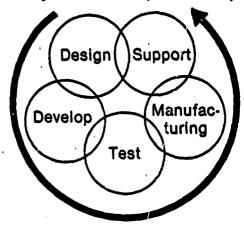
- **Replace all conventional drawings**

- **Used to communicate product definition to engineering, manufacturing, customers, suppliers, partners, FAA, etc.**

- **Foundation for concurrent engineering methods**

- **Enable further automation of applications over the product life cycle**

- **Application to ATF airframe and engines**

COMPUTERIZED PDD - TODAY

- **Database is incomplete and redundant**

- **Communication difficult and limited**

- **Few life cycle applications**

- **Technical and management issues need attention**
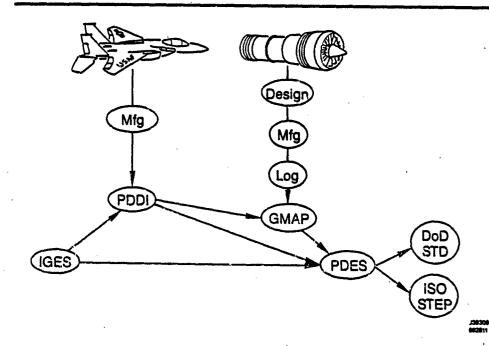
PROGRAM OBJECTIVE

- Establish product definition data transfer over the life cycle of complex components

CP3374-12
R882305

NEAR-TERM DIRECTION FOR PDD TECHNOLOGY

J38306-6
882911 art

LIFE CYCLE OF PRODUCT DEFINITION STANDARDS

Development
R&D
Proof-of-concept
Demonstration

→ Developers use

Specification
Industry understanding
Further refinement
Technical agreement

→ Some commercialization

National standard
Commercial commitment

Government contract requirement
Aerospace commitment
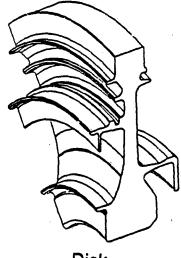
→ Widespread use

Time →

CP3988-10
881107
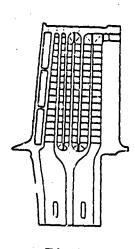
GMAP STUDY PARTS

Disk   Blade

J38308-8
882911 rm1
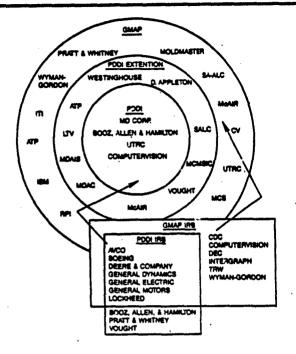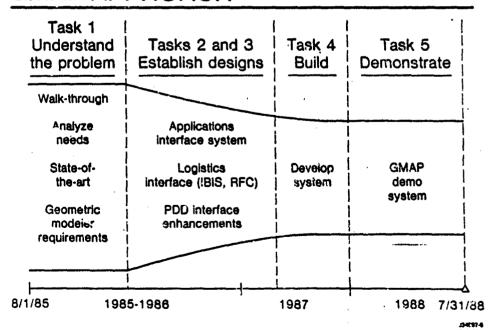
GROWING INDUSTRY COMMITMENT TO AIR FORCE SPONSORED INITIATIVES

GMAP

PRATT & WHITNEY   MOLDMASTER

PDDI EXTENTION

WYMAN-GORDON   WESTINGHOUSE   D. APPLETON   SA-ALC

ATP   PDDI   McAIR

MD CORP.

LTV   BOOZ, ALLEN & HAMILTON   SALC   CV

ATP   UTRC

MDAIS   COMPUTERVISION   MCMSIC   UTRC

IBM   MDAC   VOUGHT   MCS

RPI   McAIR

GMAP IRB

PDDI IRB
- AVCO
- BOEING
- DEERE & COMPANY
- GENERAL DYNAMICS
- GENERAL ELECTRIC
- GENERAL MOTORS
- LOCKHEED

BOOZ, ALLEN, & HAMILTON
PRATT & WHITNEY
VOUGHT

CDC
COMPUTERVISION
DEC
INTERGRAPH
TRW
WYMAN-GORDON

GMAP APPROACH

Task 1 Understand the problem	Tasks 2 and 3 Establish designs	Task 4 Build	Task 5 Demonstrate
Walk-through			
Analyze needs	Applications interface system		
State-of-the-art	Logistics interface (IBIS, RFC)	Develop system	GMAP demo system
Geometric modeler requirements	PDD interface enhancements		

8/1/85   1985-1986   1987   1988   7/31/88

WALK-THROUGH FLOW

FUNCTION ANALYSIS

- Resulted in function model roadmap consist
  - 319 activities
  - Representing 102 functions
  - 50 functions selected for information analysis

- Pratt & Whitney functions within:
  - Design and analysis
  - Manufacturing and inspection
  - Product support

- Supplier functions within:
  - Manufacturing and inspection

- Logistics functions within:
  - Replacement manufacturing, refurbishment, inspection

MAJOR FUNCTIONAL AREAS

Design and analysis

- Preliminary engineering design

- Detailed blade and disk design a
  analysis

- Final blade and disk design and

- Detailed engineering specification

MANUFACTURING AND
INSPECTION FUNCTIONAL AREAS

Manufacturing
- Casting process planning
- N/C programming — molds and dies
- Categorize and review parts and processes
- General process planning
- Tool design
- N/C programming disk machining
- N/C programming — laser hole drilling

Inspection
- Quality requirements engineering
- Programming automated inspection devices

J39308-13
882811 m1

PRODUCT SUPPORT/LOGISTICS
SUPPORT FUNCTIONAL AREAS
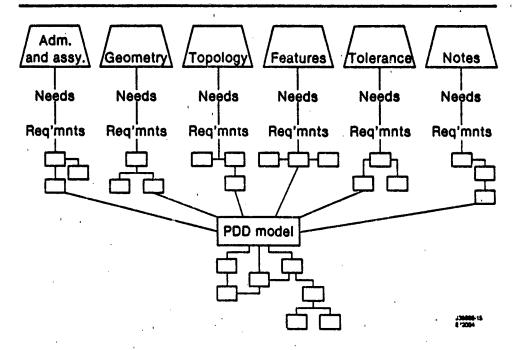
Product support
- Provide technical support
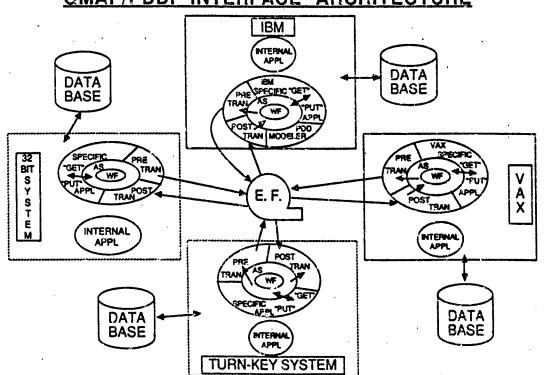
Logistics support
- Product maintenance
- IBIS (Integrated Blade Inspection System)
- RFC (Retirement for Cause)

J39308-14
882811 m1
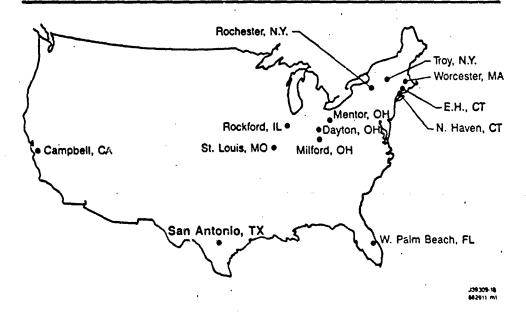
WHAT WE DID...

GMAP/PDDI INTERFACE ARCHITECTURE

GMAP DEMONSTRATION SITES

Rochester, N.Y.
Troy, N.Y.
Worcester, MA
E.H., CT
Mentor, OH
N. Haven, CT
Rockford, IL
Dayton, OH
Campbell, CA
St. Louis, MO
Milford, OH
San Antonio, TX
W. Palm Beach, FL

J39309-18
862911 mt

GMAP DEMONSTRATIONS
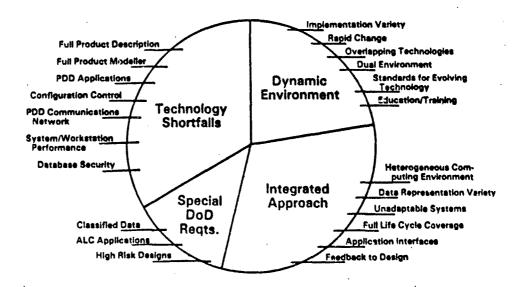
Blade	• Parametric blade design	• Casting tooling	• IBIS
Disk	• Disk design	• PROCAP • Feature based N/C & CMM programming • Disk forging	• RFC
Other		• Case boss inspection • PDDI parts	

Design   Mfg and inspection   Product and logistics support

Life cycle

J38714-3
871704

SPECIFIC CONTRACTUAL DEMONSTRATIONS

- Exchange Format
- Access software
- Supplier base integration
- GMAP using PDDI part classes
- GMAP—IBIS interface
- GMAP—RFC interface

J30714-2
871704

TECHNICAL ISSUES IN PRODUCT DATA TRANSFER

Full Product Description
Full Product Modeller
PDD Applications
Configuration Control
PDD Communications Network
System/Workstation Performance
Database Security

Technology Shortfalls

Dynamic Environment

Implementation Variety
Rapid Change
Overlapping Technologies
Dual Environment
Standards for Evolving Technology
Education/Training

Integrated Approach

Heterogeneous Computing Environment
Data Representation Variety
Unadaptable Systems
Full Life Cycle Coverage
Application Interfaces
Feedback to Design

Special DoD Reqts.

Classified Data
ALC Applications
High Risk Designs

THE 1990s

- **PDES commercialized**

- **Networks with two way flow**

- **Product process modeler software**

- **Application**
  - Design - full
  - Manufacturing - Near full
  - Logistics - Some

GMAP — ONE OF SEVERAL AIR FORCE PROJECTS WHICH SUPPORT PDD

- Product Definition Data Interface (PDDI)

- Digital product models for ATF

- Integrated Information Support System (iISS)

- Spare Parts Production and Reprocurement Support System (SPARES — 89 start)

- Integrated Design System (IDS)

- Engineering Information System (EIS)

STARS/SW PRODUCIBILITY

Briefing to DARPA CD/CE Workshop
STARS Software-First Life Cycle

6 December 1988

Jim Moore
(301) 240-7843
moorej@ajpo.sei.cmu.edu

IBM Systems Integration Division
18100 Frederick Pike
Gaithersburg, MD 20879

IBM's Plan

Exploit

- Existing technologies for developing machine-independent software
- Emerging standardization of functional interfaces

To develop a new Software-First Life Cycle

Supported by

- A software development environment facilitating

  Prototyping

  Evaluation

  Selection

- A repository of

  Software components

  Application paradigms

Problems with Software Development Today

Costs Too Much

Takes Too Long

Fails to Meet Requirements

Reinvention of the Wheel

Obsolescent Hardware

Obsolete Requirements

Cost Overrun

Late Operational Capability

Key Points in the Waterfall Life Cycle

SYSTEM DELIVERED

DOES THE SW FIT?

IS THE HW OBSOLESCENT?

DOES THE PRODUCT MEET THE REQUIREMENTS?

DID THE REQUIREMENTS CHANGE?

IS THIS TOO LONG?

HW SELECTED

REQUIREMENTS FROZEN

NEED PERCEIVED

DOD-STD-2167A Life Cycle

The Effect of Delaying Hardware Selection

Performance per real dollar doubles every three years.

"Taking into account the inflation rate...the 1985 cost per MIPS in real terms was 39.63 of its 1981 level, corresponding to a compounded real decline rate of about 22 percent per annum."*

* Haim Mendelson, Economies of Scale in Computing. *Communications of the ACM,* 30:12, December 1987, pp. 1066-1072. Data is based upon 95 commercially available systems in 1981 and 212 systems in 1985.

The Waterfall Life Cycle in Practice

Traditional Approach to Risk Reduction

Risk is accepted only when the proposal is submitted.

Risk is minimized during the execution of the program:

* Total program risk is minimized by minimizing the risk at each stage of the program.

* Innovative approaches are discarded in favor of conservative technologies.

* No experimentation in breakthrough technologies.

* No search for alternatives.

* Emphasis is upon *meeting* requirements at minimum cost.

Incremental approach to quality assurance:

* Inspections compare intermediate product with prior intermediate product.

The Effect of Delaying Requirements Freeze

Reduces the amount of time for the actual requirements to evolve out from under the specifications

Permits user experimentation with capabilities provided by prototypes

* To select the best of alternatives

* To help formulate new capabilities

* To help refine existing capabilities

Permits the user to verify that system capabilities match his requirements

Reduces the amount of time for the adversary to react

An Alternative Approach to Risk Reduction

Risk is accepted throughout the life cycle.

Risk is managed by cultivating alternative paths to success.

- Alternative solutions are developed and evaluated throughout the program.

- A portion of the budget is spent looking for breakthroughs.

- Emphasis is placed on finding *best of breed* solutions.

Global approach to quality assurance:

- Prototyping is used to ensure that capabilities are satisfactory to the user.

The Effect of Compounded Risk

An example:

Seven Phases of Software Development Cycle

Twenty CSCIs in System

Net Chance of System Meeting Requirements

< 25 %

Assume that each development phase introduces only a 1% risk of meeting requirements.

An Alternative Life Cycle

System Development

REQMTS FROZEN

HARDWARE FROZEN

PRODUCTIZE — EVALUATE & SELECT — BUILD PROTOTYPE SYSTEM — DEVELOP COMPO-NENTS

SELECT HARDWARE

SELECT COMPO-NENTS

REPOSITORY

Component Development

PRODUCTIZE — EVALUATE & SELECT — BUILD PROTOTYPE — CONSIDER BREAKTHRU SOLUTIONS

DESIGN ALTERN-ATIVES

CUSTOMIZE

SELECT CANDIDATE COMPO-NENTS

A New Approach to Software System Development

Do the Software Before Freezing the Requirements
- Permits the user to experiment with the prototype
- Reduces the problem of requirements evolution

Do the Software Before Freezing the Hardware
- Permits use of the most modern hardware
- Improves portability of software

Prototype Alternative Solutions
- Improves agreement with user's requirements
- Reduces technological and programmatic risk

Reuse Existing Software Components
- Reduces expense
- Selects best of breed
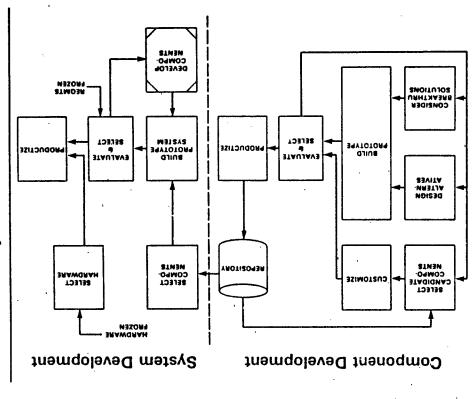
Assemble System via Selection rather than via Construction

SPEAKER PRESENTATIONS

INTERFACE STANDARDS (PANEL #5)

INTRODUCTION TO INTERFACE STANDARDS

NIST

Panel #5, Interface Standards

Chair: Mr. Howard M. Bloom, NIST

Members: Dr. T. Hopp, NIST

Mr. L. Patrick, DACOM

December 8, 1988
DARPA Concurrent Design/
Concurrent Engineering
Workshop

Introduction to Interface Standards

Howard M. Bloom
National Institute of Standards and Technology
December 8, 1988

Premise:

Standards are Partners to Technology Development.

NIST

What are the emerging standards research issues associated with Concurrent Design and Concurrent Engineering?

NIST

Types of Standards

- Measurement Standards
- Equipment (or human) Interface standards
- CD/CE Information Standards
- Data Exchange Standards
- Architecture Standards

NIST

Measurement Standards

- Sensor Technology/On-Line Measurements
- Coordinate Measurement Machine/Off-Line
  Measurement

NIST
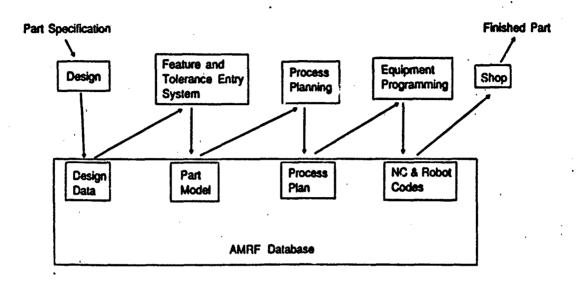
Equipment or Human Interface
Standards

- Feature Driven Machining or Inspection
- Requirements Driven Design
- Languages for Design, Process Planning,
  Manufacturing Systems and Logistics
  Support

Part Specification

Finished Part

| Design | Feature and Tolerance Entry System | Process Planning | Equipment Programming | Shop |

| Design Data | Part Model | Process Plan | NC & Robot Codes |

AMRF Database

CAD/CAM Room

NIST
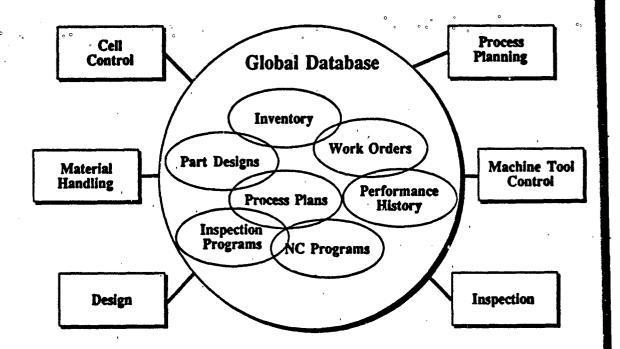
CD/CE Information Standards

- **Product Data Exchange Specification (PDES)**
  (EDIF, VHDL, etc. for Electronics Industry)

Integrated Manufacturing Database

Four Dimensions of PDES

Versions: The Scope of PDES

Topical Areas: The Technology of PDES

Levels: The Implementation of PDES

Application Areas: Use of PDES

Versions: The Scope of PDES

Design

Analysis

Planning

Production

Fabrication (assembly)

Deployment

Maintenance

Recover & Re-use

Disposal

Topical Areas: The Technology of PDES

Geometry

Topology

Shape Representation

Tolerancing

Materials

Analysis

Kinematics

Design Requirements

Features

Levels: The Implementation of PDES

Passive File

Active File

Shared DataBase

Shared Knowledge Base

Application Areas: Use of PDES

Mechanical

Electrical

AEC
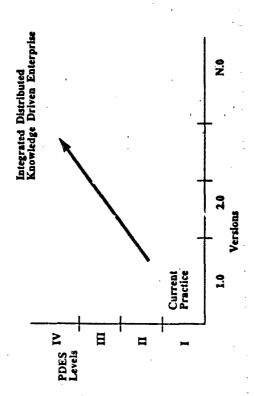
Apparel

NIST

Data Exchange Standards
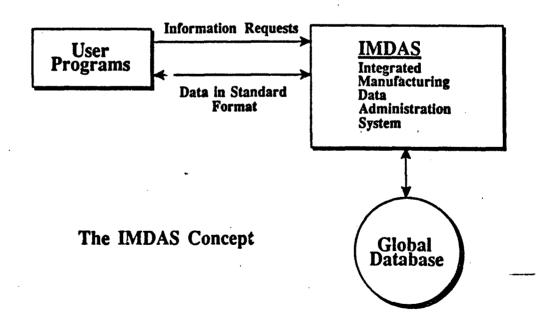
- Data Modeling Language (e.g. IDEFIX)
- Distributed Database Systems
  (e.g. IMDAS, IDS, I^2S^2, EIS)
- Network Standards (ISO/OSI Levels)
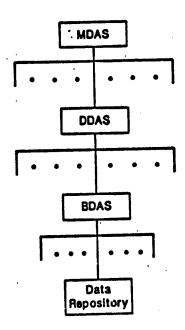- Data Directory (IRDS)

Integrated Manufacturing Data
Administration System (IMDAS)

- Generic query language (SQL)
- Distributed data management transparent
  to application
- Internal neutral format between SQL
  and commercial DBMS

```
┌─────────────┐   Information  Requests   ┌──────────────────┐
│    User     │ ───────────────────────► │ IMDAS            │
│  Programs   │                          │ Integrated       │
│             │ ◄─────────────────────   │ Manufacturing    │
└─────────────┘    Data in Standard      │ Data             │
                        Format           │ Administration   │
                                         │ System           │
                                         └──────────────────┘
                                                  ▲
                                                  │
                                                  ▼
                                            ╭──────────╮
                                           │  Global    │
The IMDAS Concept                          │  Database  │
                                            ╰──────────╯
```

The IMDAS Concept

THE IMDAS ARCHITECTURE

```
        ┌──────────┐
        │  MDAS    │          • Manages data across
        └────┬─────┘            network
    ┌─ • • • │ • • • ─┐
    └────────┼────────┘
        ┌────┴─────┐
        │  DDAS    │          • Manages LAN data dictionary
        └────┬─────┘          • Converts standard queries into
    ┌─ • • • │ • • • ─┐         neutral format
    └────────┼────────┘
        ┌────┴─────┐
        │  BDAS    │          • Converts neutral format into
        └────┬─────┘            specific query languages
    ┌─ • • • │ • • • ─┐
    └────────┼────────┘
        ┌────┴─────┐
        │   Data   │          • Communication DBMS, file
        │Repository│            manager, or memory
        └──────────┘
```

NIST

Architecture Standards
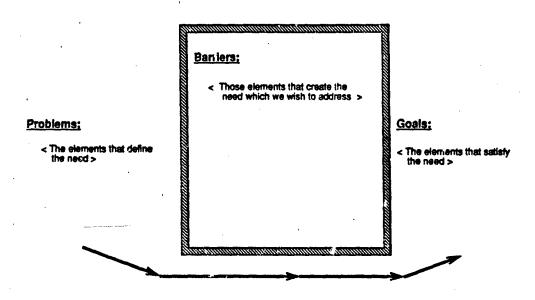
- Model for CD/CE
- implementation of PDES

NIST

Manufacturing Research Testbed

- **Needs to be addressed:**

  — Closer coupling of research efforts
  — Focusing of research efforts on key issues
  — Exposure and dissemination of technology

- **Mechanisms:**

  — Test, integrate, and showcase research systems
  — Structure a research effort in information
     technology for manufacturing

The Needs Analysis Template

Barriers:

< Those elements that create the
need which we wish to address >

Problems:

< The elements that define
the need >

Goals:

< The elements that satisfy
the need >

Strategy:

<The elements of the project effort that
overcome the barriers >

Need: Close Coupling of Research Efforts

Barriers:

- No shared lifecycle model
- Lack of standard product or process representation
- No satisfactory mechanism for communication among research systems

Problems:

- Lack of cross-fertilization among research efforts
- Missed opportunities for cooperative work
- No way to leverage individual efforts

Goals:

- Close interaction among researchers
- Integrated operation of research systems
- Synergism

Strategy:

- Develop consensus of lifecycle model
- Educate & involve research community in applicable standardization efforts
- Develop a distributed manufacturing research architecture

Need: Focus Research on Key Issues

Barriers:

- No consensus view of the evolution of manufacturing systems
- No clear boundaries for individual research efforts
- Research systems not in widespread use

Problems:

- High risk of misdirected research
- High risk of missing important technological barriers
- Long time-lag for feedback to research efforts

Goals:

- A long range research strategy that reliably identifies key issues
- Mechanisms in use to provide quick assessment of research products

Strategy:

- De   op PDES concept as a framework for identifying research needs
- Ins... , excercise, and evaluate research systems
- Assist in establishing a research strategy for DARPA/ISTO mfg. program

Need: Explore and Disseminate Technology

Problems:

- Slow payoff from new technology
- Resistance to change in the manufacturing community
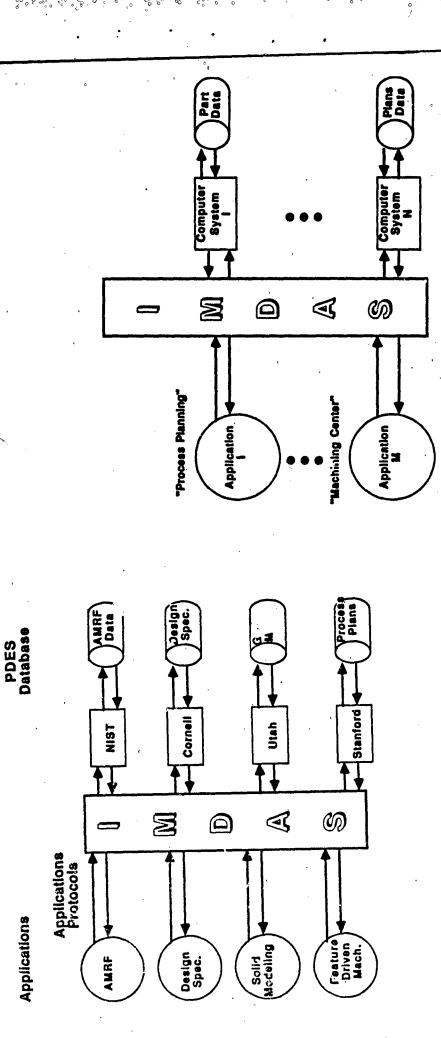
Barriers:

- Systems developed "stand-alone"
- Systems are research products
- Commercial benefits ambiguous
- New technology needs a market

Goals:

- Quick entry of new technology into U.S. manufacturing
- Benefits of new technologies easily identified

Strategy:

- Develop integration technologies based on AMRF principles
- Manufacturing research testbed as showcase
- Use NIST as stepping stone for technology transfer

AMRF
NIST

A Model of Technology Transfer

Process Research → DARPA/NIST Research Testbed → Technology Centers → Manufacturing Enterprise
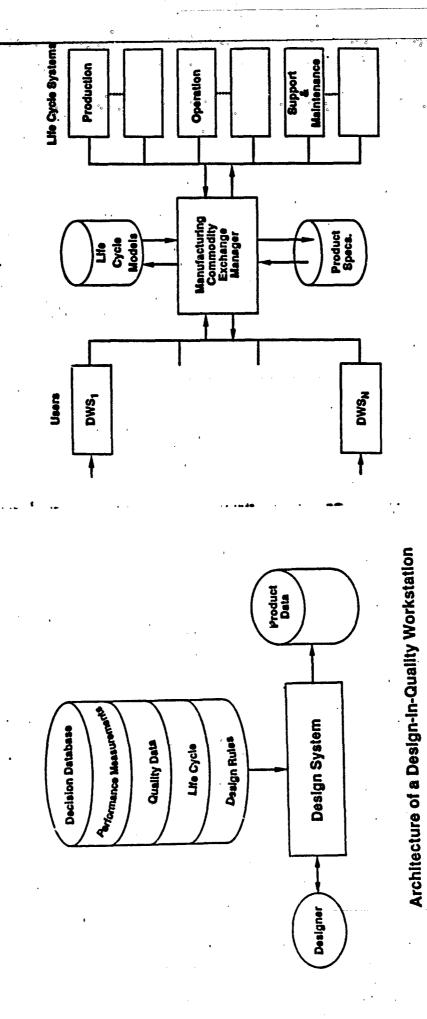
Example of PDES Testbed Implementation

Example of DARPA-NIST-University
PDES Demonstration

Manufacturing Commodity Exchange System

Life Cycle Systems:
- Production
- Operation
- Support & Maintenance

Life Cycle Models

Manufacturing Commodity Exchange Manager

Product Specs.

Users:
- DWS$_1$
- DWS$_N$

Architecture of a Design-In-Quality Workstation

Decision Database
Performance Measurements
Quality Data
Life Cycle
Design Rules

Design System

Product Data

Designer

INTERFACE STANDARDS FOR CONCURRENT ENGINEERING

Interface Standards for Concurrent Engineering

Theodore H. Hopp

National Institute of Standards and Technology
Gaithersburg, MD

DARPA Concurrent Design/Concurrent Engineering Workshop
Key West, FL
December 7, 1988

A major barrier to integration of life cycle functions has been the lack of interface standards. Standard efforts such as PDES (Product Data Exchange Specification) and CALS (Computer-aided Acquisition and Logistic Support) represent steps on the path to fully integrated manufacturing. The goals of concurrent engineering will demand system architectures that are radically different from those we see today. Developing well-defined interfaces for these new architectures will require research in several areas. One research area is in the classification and enumeration of the interfaces. This is the same as asking what are the life-cycle functions in a concurrent engineering environment. (We already see, for instance, ambiguity in the boundary between design and process planning.) Secondly, the demands on, and complexity of, the interfaces will require better tools for specifying and formalizing the interfaces, in terms of the components that share the interface, the syntax and semantics of the interface itself, and the dynamics of the interface in operation. Issues such as the relationship between geometry models, feature representations, and process representations must be further explored. A third an- of research is in technologies for implementing interfaces. There is a need for new technologies for data-driven and goal-directed behavior as we move from private, point-to-point communication using a shared data format to a global product knowledge base shared by all elements of the product life cycle, throughout the life of many products.
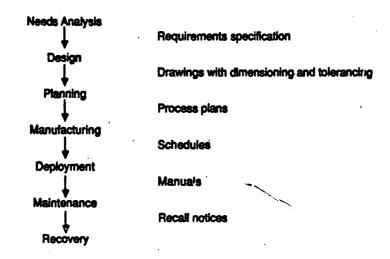
Some Issues in Interface Standards

- Classification of interfaces
- Technologies for defining interfaces
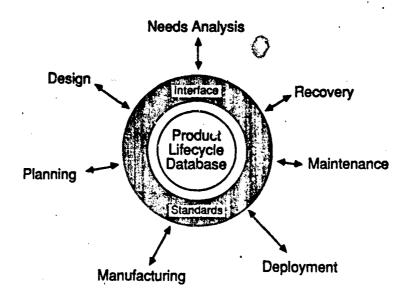- Implementation technologies
- Proprietary rights and liability

Classification of Interfaces

What are the functions?

Interfaces in Sequential Engineering

Needs Analysis

Requirements specification

↓

Design

Drawings with dimensioning and tolerancing

↓

Planning

Process plans

↓

Manufacturing

Schedules

↓

Deployment

Manuals

↓

Maintenance

Recall notices

↓

Recovery

Interfaces in Concurrent Engineering

Evolution Paths

Information Technology

Standard formats for point-to-point communication

↓

Distributed, shared product knowledge bases

Lifecycle Architectures

Traditional, sequential engineering functions

↓

Coordinated team efforts with evolving goals

Defining Interfaces

- Data and information modeling

- Modeling lifecycle functions

- Mapping between application technologies

- Interfaces are not integration

Implementation Technologies

- Standard formats

- Standard data structures

- Shared data bases

- Shared knowledge bases

Proprietary Rights and Liability

- Ownership of data

- Protection of proprietary data

- Archival data
  (the spare parts problem)

GEOMETRY AND UNCERTAINTY

GEOMETRY AND UNCERTAINTY

Ari Requicha

Programmable Automation Laboratory
Computer Science Department and
Institute for Robotics and Intelligent Systems
University of Southern California
Los Angeles, CA

SOLID MODELING: CURRENT STATUS

- **Theory**
  What is a solid, from the math point of view? (An r-set.)
  When is a representation geometrically complete? Valid?
  When is an algorithm correct?

- **Computational representations**
  CSG, BReps, octrees and other spatial partitions, sweeps, ...

- **Fundamental algorithms**
  Set membership classification
  Boolean operations
  Distances and offsets
  Representation conversions

SOLID MODELING: CURRENT STATUS (cont.)

- **Applications**
  Graphics
  Mass properties
  Static interference detection
  Robot and mechanism simulation
  NC simulation

- **Systems**
  Many commercially available
  Graphic interfaces adequate
  Substantial resources needed

SOLID MODELING: CHALLENGES

- **Complexity**
  Geometric: Free form surfaces, algebraic surfaces of arbitrary degree
  Combinatorial: Objects with > 10,000 primitives

- **Uncertainty**
  Computational: numerical errors
  Tolerances

- **Higher-level representations**
  Features, constraints, assemblies
  Functional representations. (Form from function?)

SOLID MODELING: CHALLENGES (cont.)

- **Application algorithms**
  - Finite element meshing
  - Process planning and NC code generation
  - Assembly planning and task-level robot programming
  - Inspection planning and code generation for CMMs and vision systems

- **Exploiting parallel and distributed computation**
  - Special purpose hardware, e.g., CSG-based display
  - Distributed modelers
  - Neural nets and cooperative computation

- **Engineering Environments** (analogous to Programming Environments)
  - Integrated set of tools for design, analysis, planning, simulation, ...

TOLERANCING: CURRENT STATUS

- **Theory**
  - What is a toleranced solid, from the math point of view?
  - When is a tolerance specification complete? Valid?
  - Emerging, not well understood

- **Computational representations**
  - Through limits on parameters
  - Through attributes, analogous to ANSI standards for geometric tolerances
  - Semantics not rigorously understood

- **Algorithms**
  - Tolerance analysis, based on vector loops. Worst case or statistical.
  - Integration with solid models emerging.

(POTENTIAL) TOLERANCING ALGORITHMS

- Analysis of the effects of component tolerances on assemblies

- Allocation of tolerances to components given assembly requirements

- Generation of inspection plans and instructions for CMMs

- Generation of manufacturing and assembly plans

- Synthesis of tolerance specifications from higher-level (functional) information

1988 NSF WORKSHOP ON TOLERANCING

- Current practices and standards

- Theoretical foundations and computer representations

- Analysis and synthesis in design

- Characterization, planning and execution of manufacturing processes

- Inspection methods and machines

- Assembly, reliability, maintainability, and other life cycle considerations

MAJOR NEEDS

- **Math foundations for current standards and theories**

- **Functional adequacy of current standards and theories**

- **Integration of tolerances in geometric modelers**

- **Analysis and synthesis algorithms, and their use in design**

- **Relationships between manufacturing processes, costs, and tolerances**

- **Relationship between sampling inspection methods (as used in CMMs) and tolerance specs that constrain all points on a surface**

- **Inspection algorithms**

1988 NSF WORKSHOP ON MECHANICAL TOLERANCING

Research Opportunities in Theoretical Foundations and Computer Representations

1) Develop mathematical foundations, independent of computer representations. Do tolerances specify a deterministic class of sets (a variational class)? If so, how are these classes characterized mathematically?

2) Develop or refine a mathematically defined semantics for current standards and theories.

3) Assess existing standards and emerging theories from the points of view of design and assembly. Are the functional (including assemblability) requirements of parts adequately captured? If not, how should theories be modified? Are new standards needed? Do we need to capture design intent more directly? Can tolerances be derived from higher-level specifications?

4) Investigate the relationship between sampling inspection methods (as used in CMMs) and tolerance specifications that constrain *all* points on a surface. Should sampled measurements be explicitly acknowledged in the tolerance specifications?

5) Extend theories to assemblies, including mechanisms.

6) Study representational issues. Is there a "complete" representation for tolerances, from which all oth ˆrs may be derived? Should there be different representations for design, manufacturing, inspection, and other applications? If so, how do we convert algorithmically between them? Can theories based on constraining parameters of surfaces deal with form variations? If so, are different sets of parameters needed for design, manufacturing and inspection? Should tolerance zones be represented explicitly? Must toleranced relationships between geometric entities be binary, or are n-ary relationships allowable and useful? To what extent should tolerance specifications be influenced by manufacturing and inspection concerns?

7) Establish sound criteria for assessing current and future systems for computer-based tolerancing.

8) Develop user interfaces that hide the mathematical complexity of tolerancing, and facilitate proper functional specification and interpretation for manufacturing, analysis, and inspection.

KNOWLEDGE REPRESENTATION AND DEPENDENCY

IN CONCURRENT DESIGN

**KNOWLEDGE REPRESENTATION
AND DEPENDENCY IN CONCURRENT DESIGN**

Dr. C.J. Russo
GE Aircraft Engines
Lynn, MA

DARPA CONCURRENT DESIGN / CONCURRENT
ENGINEERING WORKSHOP

December 6-8, 1988

CURRENT SYSTEMS

Geometry Focused Systems | Behavior Focused Systems
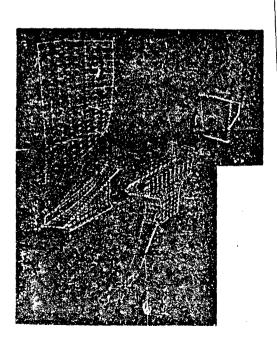
CAD/CAM systems | aero codes

DEPENDANT FEATURES

manuf. process planning | mech. codes

assembly | material property codes

Most Production Cost Control Activities | Most Design Iteration Activities

MAJOR BOTTLENECKS

aero design

   functional features
   geometry features

footprint constraints

   airfoil shape -- camber
              stagger
              chordwise thickness
              etc.

   loading --   stacking
              spanwise thickness
              etc.
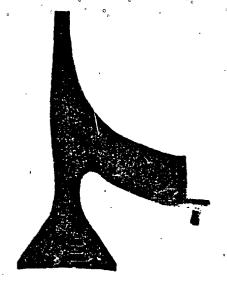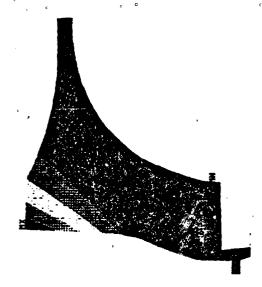
mechanical design

   functional features
   geometry features

material properties

EVOLVING TECHNOLOGIES
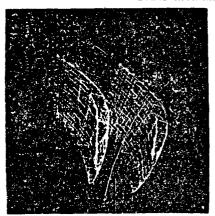
Conventional Material   Composite Material
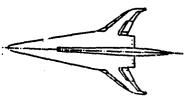
- "parameterized features" not adequate -- higher abstraction level required

- dramatically different and largely unknown functional & geometric dependancies

ENABLING METHODOLOGIES

Internal Aerodynamics

External Aerodynamics

Design Feature Definition
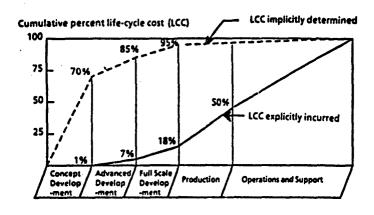
- functional features

- geometry features

Dependancy Models

- apriori knowledge

- generate during design process

Interface Methodologies

- other disciplines
  mechanical systems
  costing models, etc

- other system components
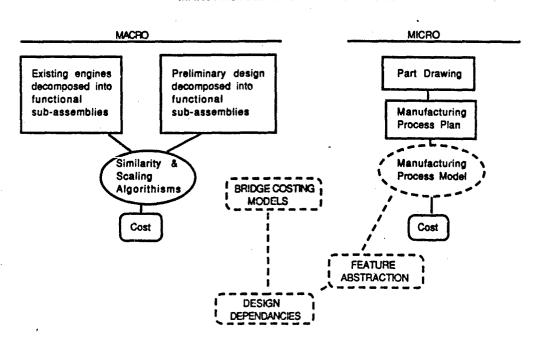 compressors & turbines

Preliminary Design Impact on LCC

Cumulative percent life-cycle cost (LCC)

LCC implicitly determined

100	85%	95%		
75 — 70%				
50			50%	LCC explicitly incurred
25		18%		
1%	7%			
Concept Develop -ment	Advanced Develop -ment	Full Scale Develop -ment	Production	Operations and Support

(DATA OBTAINED FROM BOEING)

> ## PD has large impact on LCC

GE Aircraft Engines

MANUFACTURING COST PROCESSES

MACRO

Existing engines decomposed into functional sub-assemblies	Preliminary design decomposed into functional sub-assemblies

Similarity & Scaling Algorithisms

Cost

BRIDGE COSTING MODELS

DESIGN DEPENDANCIES

MICRO

Part Drawing

Manufacturing Process Plan

Manufacturing Process Model

Cost

FEATURE ABSTRACTION

BASIC TOOLS & RESEARCH ISSUES

- Feature Definition & Manipulation Techniques

    - multiple views (aero designer to value process engineer)
    - multiple abstraction levels (conceptual to detail design)
    - shape manipulation methods (loading distributions and airfoil contours)

- Dependancy Models

    - use apriori dependancy knowledge to direct search
    - modify & generate key dependancies during design process
    - be scaleable to large systems
    - track driving dependancies for review & documentation

- Integration & Interface Tools

    - use knowledge-based systems to connect & drive CAE systems
    - toolkit for capturing knowledge & modelling processes

- Constraint Modelling & Management

    - makes resulting designs "reasonable"
    - some need to be functions of dependancies
    - heuristic constraints play a significant role

RELATED RESEARCH ISSUES

- Parallel & distributed processing

    - simultaneous & sequential analyses on coorperating hardware
    - decomposition methods for complex systems

- Deduction & Learning

    - limited apriori knowledge
    - deduce key dependancy information
    - provide design insight

- Innovative user interfaces that form a collaboration with designer

    - highly interactive
    - shared decision authority and feature definition
    - adaptive to experience level
    - tailored to designer point of view & language

APPENDIX C

LIST OF ATTENDEES

DARPA CONCURRENT DESIGN (CD)/CONCURRENT ENGINEERING (CE) WORKSHOP

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DECEMBER 6-8, 1988

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Panel #1
Features as Knowledge Representation
Dr. Jay M. Tenenbaum - Chair

Prof. John Dixon
Prof. Susan Finger
Prof. Barry W. McNeill
Mr. Daniel Neff
Dr. Carol J. Russo

Panel #2
Man-Machine Interface
Dr. Y.V. Ramana Reddy - Chair

Dr. Joseph W. Erkes
Mr. Roger Morenc
Prof. John Williams

Panel #3
Concurrent Engineering Methodology/Partitioning
Dr. Ralph Wood - Chair

Prof. John Dixon
Dr. Richard F. Riesenfeld
Prof. James Rinderle
Dr. Michael Wozny

Panel #4
Theory of Geometry/Tolerance Representations
Prof. Ari Requicha - Chair

Dr. David Gossard
Dr. Joshua Turner

Panel #5
Interface Standards
Mr. Howard Bloom - Chair

Dr. Theodore H. Hopp
Mr. Larry Patrick

Panel #6
Intelligent Database Design and Network Support
Mr. Roger Burkhart- Chair

Dr. Jean-Pierre DeJean
Prof. Martin Hardwick
Dr. Richard A. Volz

Panel #7
CD Architecture Capability/Technology Needs
Dr. Clinton W. Kelly, III - Chair

Dr. Mark Fox
Dr. J. W. Lewis

Panel #8
Application Reaction
Mr. D. T. Engen - Chair

Mr. Kevin Blackwell
Dr. G. D. Goldshine
Mr. William C. Huber